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EFFECTS OF POST-IMPOUNDMENT SHORE MODIFICATIONS ON FISH POPULATIONS IN MISSOURI RIVER RESERVOIRS

DEC 3 1980

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
RESEARCH REPORT 80

RESEARCH REPORTS

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Library of Congress Cataloging in Publication Data

Benson, Norman Gustaf, 1928-
Effects of post-impoundment shore modifications on fish populations in Missouri River reservoirs.

(Research report—U.S. Fish and Wildlife Service ; 80)
Includes bibliographical references.
1. Fishes—Effect of water levels on. 2. Fishes—Missouri River Basin—Ecology. 3. Reservoirs—Shorelines. 4. Reservoir ecology—Missouri River Basin. I. Title. II. Series: United States. Fish and Wildlife Service. Research report—U.S. Fish and Wildlife Service ; 80.
SH11.A3 no. 80 [SH173.5] 639.9'0973s [639.9'77] 80-21800

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By Norman G. Benson

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Research Report 80
Washington, D.C. • 1980

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Effects of Post-impoundment Shore Modifications on Fish Populations in Missouri River Reservoirs

by

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Abstract

In the Missouri River main stem reservoirs in Montana, North Dakota, and South Dakota, hydrodynamic processes have decreased the lengths of shorelines and changed their configuration during the first 20 to 25 years of impoundment. Shale shores of Lakes Fort Peck, Oahe, Sharpe, and Francis Case were rapidly eroded by wave action and water level fluctuation. Banks slumped, embayments filled, and stumps and debris were covered by sediment. Shale shores developed mean slopes of 5-7% in sections of reservoirs with 10- to 25-km fetches and more than 10% in sections with 3- to 7-km fetches. Glacial till tended to armor the shorelines and deter their degradation in all reservoirs. Bank-cutting was particularly severe up to 1973 in the readily erodible Fort Union sediments along Lake Sakakawea. Water level fluctuation retarded the development of stable shores. Some aquatic vegetation developed along shorelines and in shallow sections of reservoirs in which water levels fluctuated little. Substrate suitable for terrestrial vegetation did not develop along the shores of fluctuating reservoirs, except where alluvial deposits were present. Physical changes of the shore probably influenced fish abundance and species composition primarily by changing the quality and quantity of spawning and nursery habitat. Species that appeared to be adversely affected by shore changes required protected embayments or flooded vegetation for reproduction: white crappie, *Pomoxis annularis*; black crappie, *P. nigromaculatus*; yellow perch, *Perca flavescens*; northern pike, *Esox lucius*; bigmouth buffalo, *Ictiobus cyprinellus*; smallmouth buffalo, *I. bubalus*; and carp, *Cyprinus carpio*. Fish that spawn in tributaries or along rocky shores were not greatly influenced by shore changes (although the growth rate of several species was slowed): sauger, *Stizostedion canadense*; channel catfish, *Ictalurus punctatus*; white bass, *Morone chrysops*; goldeye, *Hiodon alosoides*; and river carpsucker, *Carpiodes carpio*. One species, the walleye, *Stizostedion v. vitreum*, appeared to be benefited by the shore changes. Physical changes along shores have not been adequately addressed in reservoir ecological planning. Fish population data collected before reservoir shores have reached a reasonable degree of stability do not provide a reliable estimate of the ultimate species composition in a reservoir.

Physical changes on reservoir shores have not been adequately considered as factors influencing changes in fish abundance or species composition in new reservoirs. There is evidence in the Missouri River main stem reservoirs that the entire shore modification process strongly influenced changes in fish species composition during the early years of impoundment. To describe this influence of shore modification, I review the process of shore modification in reservoirs in general, discuss shore changes in the Missouri River reservoirs, and review data on the possible effects of these changes on the species composition and abundance of fish in the Missouri River reservoirs.

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Development of Shores in Reservoirs

Both the shore slope (a vertical change) and the shore configuration (a horizontal change) in reservoirs are modified as the reservoir ages and the shore changes. Both aggradation and degradation are involved in the process. The most rapid erosion of shores takes place during the early years of impoundment, or when shores are first submerged (Twenhofel 1961). When a large reservoir first inundates an incised river valley, deep bays and long headlands with deep water may occur near shore. Waves rapidly erode cliffs on the newly exposed shore and transport material alongshore or offshore into the reservoir. Rapid degradation of exposed headlands begins early.

Embayments become cut off from the main body of the reservoir when the transported eroded sediments alongshore accumulate as sandbars at their mouths. Hydrodynamic processes work to shorten the length of the shores and create conditions that enable currents to function with minimum energy losses as shore configuration becomes more uniform (Zumberge and Ayers 1964). With the passage of time, an equilibrium offshore slope develops that includes a wave-cut platform or beach, which reduces the energy of the waves by bottom friction. Hutchinson (1957) defined an equilibrium slope of a lake shore as one that was not altered by erosion processes, and doubted whether any such slope existed or would ever develop. A geological glossary (Gary et al. 1972) defines the profile of equilibrium as the slightly concave slope of the floor of a sea or lake, taken in a vertical plane and extending away from and transverse to the shoreline, and having a gradient such that the amount of sediment deposited by waves and currents is balanced by the amount removed by them. Such stable shorelines have reached a high degree of equilibrium over long periods, and normally change only as a result of drastic or catastrophic events such as severe storms, floods, or droughts.

The development of equilibrium slopes takes place much more rapidly in man-made reservoirs than in natural lakes because a reservoir is formed by the very rapid inundation of the valley floodplain and exposure of the existing landforms to hydrodynamic processes. The developing shore may recede, remain stable, or accumulate additional material. Receding or stable shores are the most common, except where deltas form at the mouths of inflowing streams. Stable shores are usually composed of rock or other erosion-resistant material. Receding banks may undergo simple abrasion or may slump. Slumping encompasses all forms of bank removal that involve the movement of sections of earth or rock into the reservoir, in contrast to the movement of small individual rocks or soil particles by simple abrasion. During the early years of impoundment, slumping is more prominent than abrasion because beaches have not formed to reduce the energy of the waves, and the shore has exposed promontories.

Prediction of the rate of development of shore configuration and slope will always be difficult in reservoirs because of wide variations in bedrock formation, surficial deposits, wave action, water levels, currents, wind, ice, and precipitation. The equilibrium slope that ultimately develops along the shore varies greatly among different sections of a single reservoir because of variations in these same factors. (Johnson [1919] described such variations for different sections of the Lake Michigan shore.) Consequently, the development of a generalized mathematical model for prediction of shore formation in reservoirs appears improbable.

Certain background information from the literature which follows is applicable to all reservoirs: the effects of wave action, water levels, and precipitation on shore modification; records of attempts to predict shore formation in reservoirs; the time required for a shore to reach a given degree of stability; and the relations of shore erosion to sediment deposition.

Wave Action, Water Levels, and Precipitation

Wave action in reservoirs has been studied by engineers primarily because of its effects on impoundment structures (U.S. Army Corps of Engineers 1962; Saville et al. 1963). Waves form in reservoirs much as they do in oceans, except that in reservoirs the fetches

are usually shorter and wind velocity and direction are more variable because of the topography of the surrounding land. The sinuosity of many reservoirs and the effects of high banks complicate the prediction of the results of wave action. Certain general differences exist between waves in reservoirs and oceans in height, length, and period (time in seconds required for waves to pass a given point). Wave heights and other characteristics are affected by depth of the water if the depth is less than about half the length of the wave (U.S. Army Corps of Engineers 1962). Most reservoirs are deep enough to rule out depth as a limiting factor in the generation of waves. Wave steepness (ratio of height to width) depends on wave age. Reservoirs have "young waves," which are steep and have short periods; oceans have "old waves," which are flatter and have long periods (Sverdrup et al. 1942). Observational evidence indicates that wave height increases rapidly until the fetch reaches about 100 km; when fetches are longer, the rate of increase in wave height decreases and waves tend to become longer, flatter, and have longer periods. Steep waves with short periods are common in reservoirs because fetches rarely exceed 25 km. Empirical data on wave formation in three reservoirs demonstrate some of these relations (Table 1).

Table 1. *Some relations of fetch and wind velocity to wave height and wave period in reservoirs.*[a]

Reservoir	Fetch (km)	Wind velocity (m/s)	Average wave height (m)	Wave period (s)
Rybinsk and	—	6-7	0.25-0.30	—
Tsimlyanskoe (USSR)	—	13-18	0.7-0.8	—
Fort Peck (Montana)	7.2	10	0.4	2.6
	7.2	9	0.5	2.4
	7.2	14	1.4	1.4
Denison (Oklahoma)	8.0	14	1.2	2.6
	4.8	11	0.4	3.0

[a]Sources of data: Rybinsk and Tsimlyanskoe reservoirs, Zhivago and Lange (1957); Fort Peck and Denison reservoirs, U.S. Army Corps of Engineers (1962).

Waves higher than 2.5 m were reported by Zhivago and Lange (1957) on Rybinsk and Tsimlyanskoe reservoirs. Data developed by the U.S. Army Corps of Engineers (1962) showed that winds of 18 m/s generate significant (highest third in each sampling interval) wave heights of 2.1 m when the fetch is 32 km, and 3.0 m when the fetch is 64 km.

Fluctuating water levels delay and may prevent the formation of a stable slope on reservoir shores because of the continual submergence and emergence of beaches. Littoral currents and waves attack beaches at different elevations when water levels are raised or lowered. Also, high water levels may cause massive land slumping, and the process of beach formation is then repeated.

The amount of water available in landform soils (determined largely by precipitation) influences shore slumping more than abrasion. Some bluffs are vulnerable to gravity slumping simply because of weight instability. In some shale areas, extensive sliding occurs when seams of bentonite become lubricated by saturation from rainfall (Erskine 1973).

Prediction of Shore Modification and Time Required

Generalized equations for predicting reservoir shore modification are unavailable. Several Russian scientists have prepared balance equations for the reworking of banks in large reservoirs (e.g., Pyshkin 1969), but none appear suitable for general prediction. Finarov and Kolbutov (1969) suggested a geomorphological method for predicting reservoir bank transformation, based on historical information on reservoir basin relief, present relief, geological structure, designed hydrological conditions, and natural bank formation analogues on nearby reservoirs.

For land acquisition purposes, the U.S. Army Corps of Engineers determines the probable limits of the ultimate shore erosion. The calculated ultimate erosion slope represents the offshore beach slope that is sufficient to negate the wave run-up forces that attack the reservoir shores. Its attainment includes both removal and deposition of material. For Missouri River reservoir planning, the estimated ultimate erosion slope (derived from empirical data collected at the Missouri River reservoirs and others) averaged about 1 (vertical) on 12 (horizontal), or about 8%.

The time required for reasonably stable shore configurations and slopes to develop in large reservoirs appears to be 20 to 25 years. Ziminova and Kurdin (1968) found that shore

soils and slopes in Rybinsk Reservoir had stabilized to a considerable degree by about 25 years after initial impoundment, and Gurvich et al. (1972) wrote that 20 to 25 years were required to form stable bank slopes on the Dnieper River reservoirs. In Fort Peck Reservoir, Montana, which was impounded in 1937, the slopes of shale shore within the elevations of normal water operations had become fairly stable by 1961 (U.S. Army Corps of Engineers 1966).

Sedimentation

The greatest effects of shore modification on the depletion of reservoir volume by sedimentation occur during the early years of impoundment, when bank formation processes are most active. Palarmarchuk (1972) stated that during the early years of impoundment, most sedimentation in large reservoirs in the Soviet Union (e.g., Tsimlyanskoe, Dnieper) is the result of the caving in and erosion of the banks caused by wind-generated hydrodynamic activity, fluctuating water levels due to power operations, and other factors. Sokolov (1973) wrote that incoming rivers are the main source of sediment that continually depletes the volume of a reservoir, and Gottschalk (1964) stated that bank erosion usually contributes less than 10% of the total sediment load in U.S. reservoirs. Partly because this percentage is so small, bank erosion and development of shore configuration have not been studied extensively in the United States.

Delta formation at the mouths of tributary streams, an aggradation rather than a degradation process, accounts for the major portion of sediment deposition that occurs over the total life of a reservoir. Harrison (1952), who studied a series of reservoirs in the United States west of the Mississippi River, offered the following findings: (1) bed-material load (sand and gravel) drops out first and forms the uppermost end of most deltas; (2) wash load (silt and clay) remains in suspension longer, spreads out longitudinally, and may form either flocculent or firmly consolidated bottom deposits, depending on the processes of consolidation; (3) deltas tend to straighten out channels, which may have been sinuous before inundation; (4) vegetation development on deltas during low water periods often prevents further degradation; and (5) consolidation of soils on deltas is often controlled by the degree of water level fluctuation.

Modification of the Shore on the Missouri River Main Stream Reservoirs

The gross changes that have occurred in the slope and configuration of the shores of all Missouri River reservoirs during the early years of impoundment have been determined largely by the geology of the shores and the morphometry of the reservoirs. I consider these features briefly before discussing the shore modifications in each reservoir.

Geology of the Shores and Morphometry of the Missouri River Reservoirs

The geological formations along the shores of the Missouri River reservoirs consist of sedimentary deposits of shale, clay, silt, lignite, and chalk; glacial till overlies these deposits in some areas (Fig. 1). The Missouri River is near the southernmost boundary of the Wisconsin glaciation, and most deposits from this glacial period are on the north or east shores of the reservoirs in the Missouri Coteau. Thin deposits of glacial till from the earlier Kansan glaciation occur south of Lakes Sakakawea and Fort Peck. Alluvial deposits of the Missouri River trench were almost completely inundated by the filling of the main stem reservoirs. They are now exposed on the shores only in the upper ends of the reservoirs or in tributary arms where deltas are forming.

The predominant shore deposits on Lakes Fort Peck, Oahe, Sharpe, and Francis Case are various Cretaceous shales; all respond similarly to shore erosion and are vulnerable to mass soil movement. Various members of the Pierre shale group are present at Lakes Oahe, Sharpe, and Francis Case, and Bearpaw shale occurs at Fort Peck Reservoir. Seams of bentonite are interspersed in the shale beds. Erskine (1973) found that slumping or movement of Pierre shale along Lake Francis Case resulted from lubrication by water, addition of weight by water, removal of deposits at the toe of slumps, or a combination of these

Table 2. *Age, morphometric data, water levels, and sedimentation rates of Missouri River main stem reservoirs.*[a]

Lake	Year dam was closed	Year normal operating level was reached	Shoreline length (km)	Area (km^2)	Volume (km^3)	Average annual sediment inflow ($m^3 \times 10^6$)	Average annual water level fluctuation (m)	Average water level range after reservoir reached normal operating level (m above msl)
Fort Peck	1937	1942	2,446	971.3	22.1	21.6	3.7	680.9-684.6
Sakakawea[b]	1953	1955	2,156	1,489.3	28.0[b]	47.0	3.8	560.1-563.9
Oahe	1958	1967	3,620	1,440.7	27.6	39.8	2.9	490.0-492.9
Sharpe	1963	1964	322	230.7	2.3	5.4	0.6	432.8-433.4
Francis Case	1952	1953	869	384.5	5.7	20.5	8.4[c]	407.6-416.0[c]
Lewis and Clark	1955	1955	145	121.4	0.6	3.1	1.2	367.0-368.2
Total			9,558	4,637.9	86.3	137.4		

[a]Morphometric data from Omaha District, U.S. Army Corps of Engineers; shoreline length, volume, and area taken at elevation of base of exclusive flood control pool in each reservoir.
[b]Volume does not include Snake Creek sub-impoundment (Lake Audubon).
[c]Annual average water level range was 8.4 m in 1971-74 but was 10.7 m in 1954-70.

factors. The slope angle at which Pierre shale moved was inversely related to the montmorillonite content in the clay portion of the shale. He concluded that wave action and altered groundwater tables affected shale slumping along the shores.

The Lake Sakakawea shore consists of Tertiary Fort Union deposits overlain with deposits of glacial till (Bluemle 1973). The fine sand, gravel, and glacial till on the south shore are the remains of the Kansan glaciation. In the upper end of the Little Missouri Arm, the glacial till was eroded away before the reservoir was impounded, and consequently the Fort Union formation extends to the surface. The glacial till on the north shore of the reservoir includes both Kansan and Wisconsin deposits and is made up predominantly of sand and gravel. The larger glacial rocks, which are characteristic of the Missouri Coteau deposits, lie mostly to the north but reach the shore in the eastern downstream part of the reservoir. The Fort Union formation is a loosely consolidated freshwater sedimentary mixture of clays, shales, silt, and lignite. Nodules, concretions, and "clinkers" of burnt lignite occur throughout this formation.

Niobrara chalk is a soft limestone that forms the main shore of Lewis and Clark Lake and is also exposed along the shore areas of Lake Francis Case. It erodes to a steeper slope than does shale or clay.

The Upper Cretaceous Fox Hills sandstone, which forms the shore of the upstream end of Lake Oahe, is exposed near Beaver Creek and the Cannonball River. Fox Hills sandstone appears to be stabilizing at a steeper slope than does shale. Sandstone deposits are also exposed in the Big Dry Creek Arm of Fort Peck Lake. Loess deposits occur in a few areas along the east shores of Lakes Oahe and Sharpe.

Glacial till along reservoir shores adds diversity and stability. Glacial till may also form a firm armored bottom such as that described by Livesey (1965) for the tailwater below Lake Francis Case.

The estimated total length of the shore in the Missouri River reservoir system is 9,558 km. The section of shore of greatest importance to biological activity (euphotic zone) lies between the maximum water level and an elevation about 5 m below the average minimum water level. The major morphometric features of the reservoirs are listed in Table 2.

Shore Modifications of Lake Fort Peck

Inasmuch as Lake Fort Peck reached normal operating level in 1942 (earlier than the other main stem reservoirs), the process of shore formation has progressed over a longer time than in any of the other reservoirs in the Missouri River system. The reservoir is 4-6 km wide for most of its length, but a section near the dam is 25 km wide (Fig. 1). Rolling grassland and wooded areas border the reservoir and the water surface is normally 15-20 m below that of the surrounding highlands.

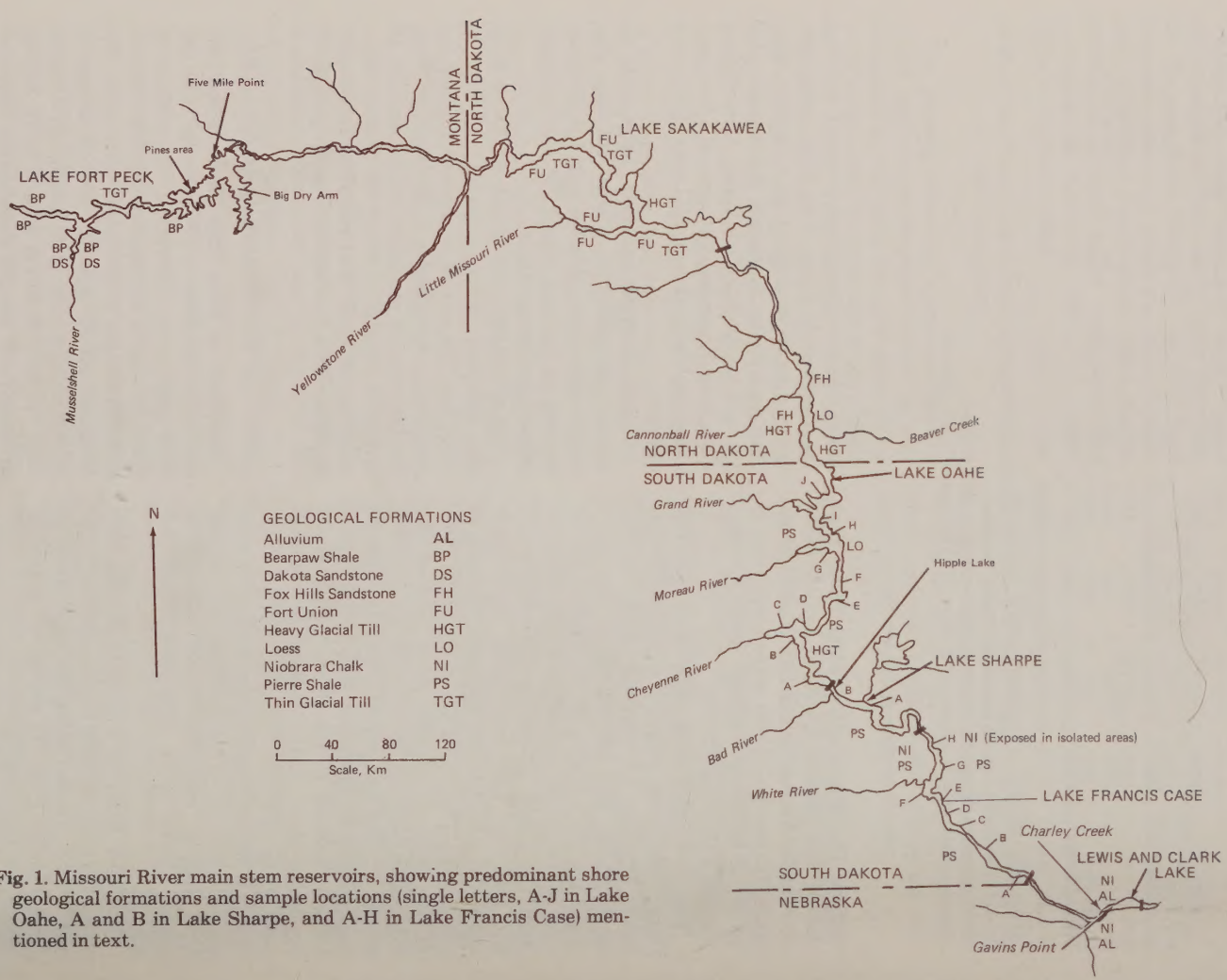

Fig. 1. Missouri River main stem reservoirs, showing predominant shore geological formations and sample locations (single letters, A-J in Lake Oahe, A and B in Lake Sharpe, and A-H in Lake Francis Case) mentioned in text.

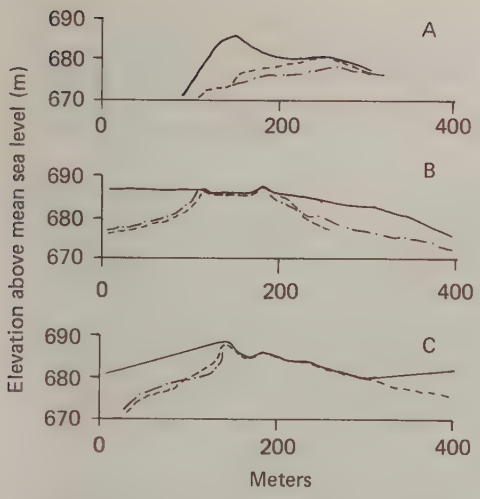

Fig. 2. Shore erosion at three cross sections of Five Mile Point at Lake Fort Peck from data collected in 1934 (solid line), 1950 (short dashes), and 1959 (dots and long dashes). Cross section A is at exposed southern tip of Five Mile Point, and B and C are 550 m and 1,303 m, respectively, north of A. Incomplete lines indicate lack of data. From U.S. Army Corps of Engineers (1966).

Detailed erosion studies of the section of shore within the elevations of 670 to 685 m above mean sea level (msl) were made by the U.S. Army Corps of Engineers (1966) at Five Mile Point and the Pines Area (Fig. 1). Five Mile Point is an exposed promontory near the dam, where the fetch is 20-25 km. This area changed drastically from 1934 (before impoundment) to 1959 (Fig. 2). Degradation was severe between 1934 and 1950, but lessened between 1950 and 1959, and the shore became fairly stable. The Pines Area, which is about 25 km upstream from the dam and where the reservoir is about 6 km wide, is more typical of most sections of the reservoir. Degradation there was less severe; between 1951 and 1959 the principal change was a smoothing of the slope and the partial development of a concave contour (Fig. 3). In exposed sections of the area (profiles A and B, Fig. 3), the mean slopes (straight line between two elevation points assumed) were 5.7 and 6.1%; in more protected areas (profiles C and D), the mean slopes were 14.7 and 8.0%. Slopes were thus more gentle in exposed areas than in protected areas.

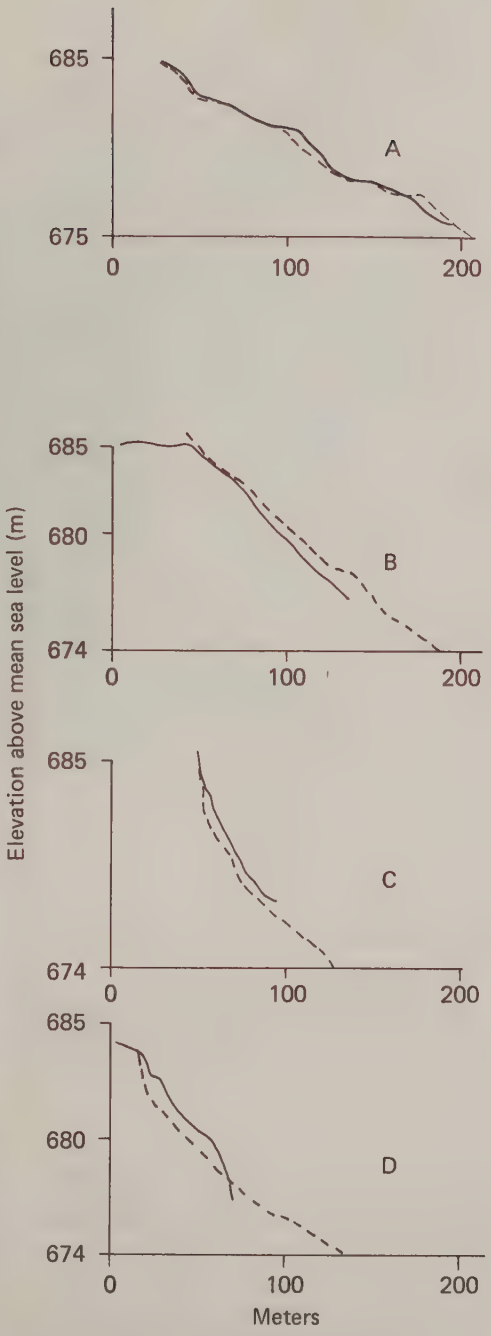

Fig. 3. Shore slopes at the Pines Area of Lake Fort Peck in 1951 (solid line), and 1959 (dashed line). Profiles A and B were exposed and profiles C and D were more protected. Incomplete lines indicate lack of data. From U.S. Army Corps of Engineers (1966).

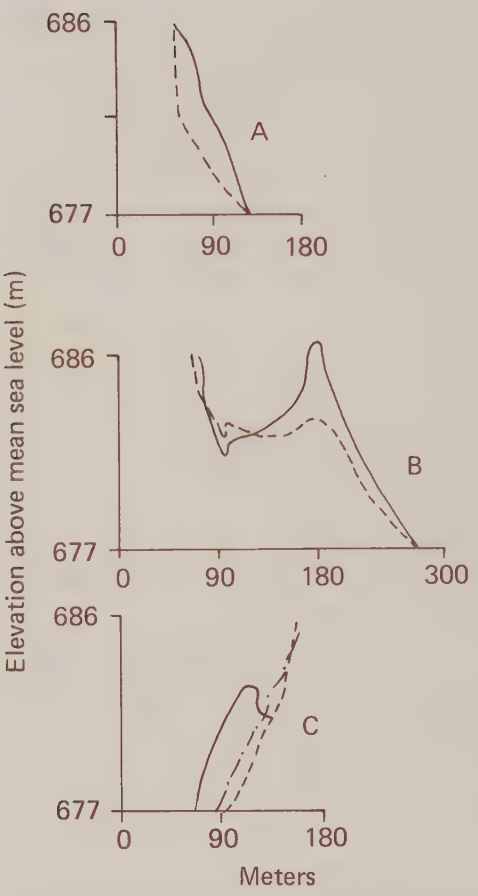

Fig. 4. Examples of shore profiles in lower Lake Fort Peck measured in 1937 (solid line), 1947 (alternate dots and long dashes; panel C only), and 1961 (dashes). Profiles are within 10 km of Five Mile Point (Fig. 1). Note the development of a concave slope in A and the removal of ridges in B and C by 1961.

About 130 aggradation ranges—profiles of reservoir bottom—have been established on Lake Fort Peck by the Corps of Engineers to measure sediment deposition in various sections of the reservoir. Four trends in shore development are evident from these profiles. First, in the lower part of the reservoir, where the fetch exceeded 20 km, heavy (10-15 m) bank cutting was common and a smooth shore with a mean slope of about 6.5% developed between 677 and 686 m above msl (Fig. 4A). Second, the slopes on shores that had fetches of more than 20 km and that were exposed to heavy wave action were stabilizing at 5-7%; steeper slopes (8-15%) developed on shores less exposed to wave action (Fig. 3D). Third, shore slope diversity diminished with time as exposed land points or ridges eroded away and adjacent depressions filled with littoral drift (Figs. 4B and 4C). Finally, the rate of change in the shore decreased rapidly after 1947. Data collected by the U.S. Army Corps of Engineers (unpublished) for 1970 showed that these slopes changed little after 1961.

Shores derived from shale develop a soft clay surface and are devoid of rocks or other debris (Fig. 5). Tree stumps were formerly present but have been buried or were removed by erosion. The slopes appear to be resistant to further degradation.

Lake Fort Peck loses about 22 million m^3 of capacity annually from sedimentation (Table 2). The heaviest buildup of sediments has occurred in the upstream end of the reservoir and off the mouths of tributaries. Alluvial inflows are the principal sources of this sediment. However, part of the accumulation of 1 to 5 m of sediment in the lower end of the reservoir from 1937 to 1961 can probably be attributed to bank erosion. Measurements of suspended sediment made in 1948-50 throughout the reservoir showed low concentrations in the downstream half of the reservoir, and there was no evidence of high-turbidity density currents (U.S. Army Corps of Engineers 1966).

Shore Modifications of Lake Sakakawea

The Tertiary Fort Union beds of clays, silts, and lignites that form the shore of Lake Sakakawea are overlain with glacial till around the entire reservoir, except in the upstream end of the Little Missouri Arm. The land immediately surrounding this reservoir is flatter and less dissected than that surrounding the other reservoirs, and the water surface is subjected to unusually heavy winds. Although the Fort Union beds are extremely erodible, the armoring with glacial till has reduced the amount of degradation, and the energy of waves and currents has developed a sand, gravel, and rocky shore along much of the reservoir (Stanley et al. 1973). In the headwaters of the Little Missouri Arm, the Fort

Fig. 5. Aerial photograph of the Pines Area, Lake Fort Peck, taken in 1964. Note lack of rocks and debris on the shore.

Union beds of clay, silt, and lignite form the shore. The movement of sand, silt, and clay along the shore by littoral currents and wave action has sealed off many of the small inlets or bays, and the mouths of intermittent streams. Extensive bank-cutting of the Fort Union beds was still occurring in 1973, primarily because beach development had been retarded by fluctuating water levels and the presence of deep water immediately offshore.

The shore slopes along Lake Sakakawea are steeper in the upstream (narrower) part of the reservoir than in the downstream (wider) section. Excluding the bottom alluvial deposits, the mean shore slopes range from 12 to 16% in the upper part of the reservoir (Fig. 6A) and from 6 to 8% (Fig. 6B) in the lower part. Slopes of the clay shore of the upper Little Missouri Arm range from 9 to 11%. Because of the large amount of glacial material present, Lake Sakakawea will probably develop a sandy shoreline, similar to that of glacial lakes in the vicinity of the reservoir; however, bank-cutting of the Fort Union deposits will recur during periods of high water.

Shore Modifications of Lake Oahe

The dam impounding Lake Oahe was closed in 1958 and the reservoir reached normal operating level in 1967. June (1974) reviewed some of the available data on sedimentation and shore erosion: (1) The average annual rate of deposition was 25 million m^3 in 1958-63, and 35 million m^3 in 1964-68; (2) deposition was heaviest in the downstream third of the reservoir, including the Cheyenne embayment, and the depth of deposits decreased progressively upstream; and (3) mass slumping of Pierre

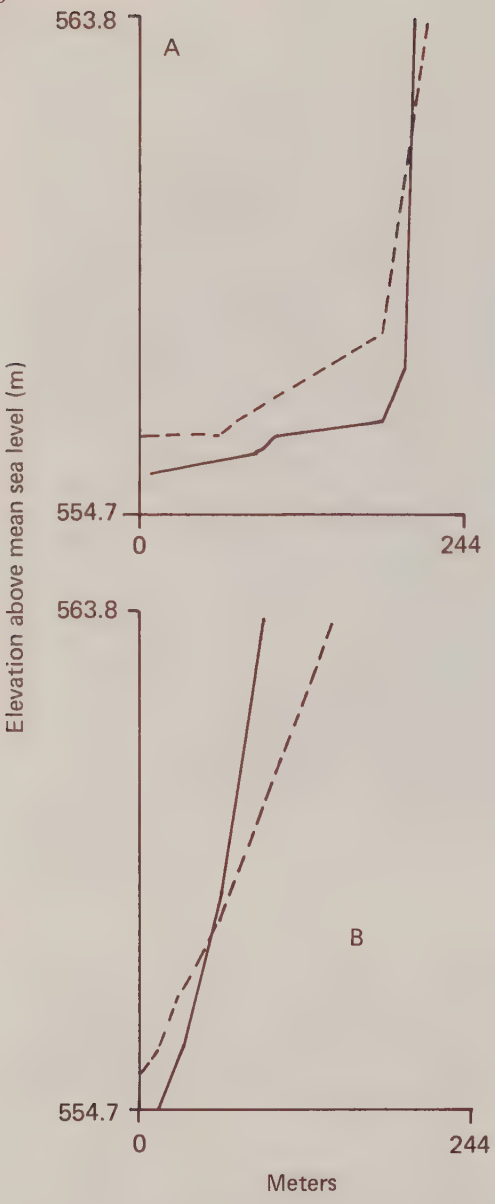

Fig. 6. Representative south shore slopes of Lake Sakakawea in 1954 (solid line), and 1969 (dashed line) at points 268 km above dam (A) and 48 km above the dam (B).

shale occurred on the west shore of the lower part of the reservoir.

Only shore changes between 481.5 and 493.8 m above msl are considered in Lake Oahe because the euphotic zone usually occurs within this elevation range. Bank-cutting was most evident in the lower end of the reservoir until 1968 because this area had been impounded for the longest period. The amount of bank-cutting that has occurred can be judged from the changes in width of the reservoir at specific cross sections and elevations (Table 3). From 1963 to 1968, bank-cutting in the downstream part of the reservoir (stations A and B, Table 3) exceeded 40 m at 490.7 m above msl. In the tributaries (station C) and in the upstream end of the reservoir (stations G, I, and J), it was much less.

Table 3. *Changes in width of Lake Oahe at elevations 484.6 m above mean sea level (elevation 1 in left column of table), 487.7 m (elevation 2), and 490.7 m (elevation 3) from 1958–59 to 1963 and 1963 to 1968 at different localities.*[a]

Station and elevation	Width (m) in 1958–59	Changes in width (m) 1958–59 to 1963	Changes in width (m) 1963 to 1968
A			
1	3,472	61.0	13.1
2	4,437	0.6	22.5
3	4,801	0.0	45.4
B			
1	4,090	−0.9	6.7
2	4,129	−0.3	20.1
3	4,173	−0.3	43.9
C			
1	1,862	0.0	7.0
2	1,935	0.0	−8.5
3	1,980	0.0	7.0
D			
1	2,373	0.0	11.6
2	2,403	−0.6	13.7
3	2,445	0.0	25.6
F			
1	2,033	−0.9	11.3
2	2,088	0.6	7.3
3	2,302	3.1	3.4
G			
1	2,186	−0.6	9.4
2	2,236	0.0	3.7
3	2,392	0.0	−2.4
I			
1	2,043	0.0	−8.5
2	2,088	0.0	0.0
3	2,302	0.0	4.9
J[b]			
1	1,522	—	−0.6
2	1,728	—	4.0
3	1,887	—	4.0

[a]See Fig. 1 for locations of stations.
[b]Difference determined only for 1963–68.

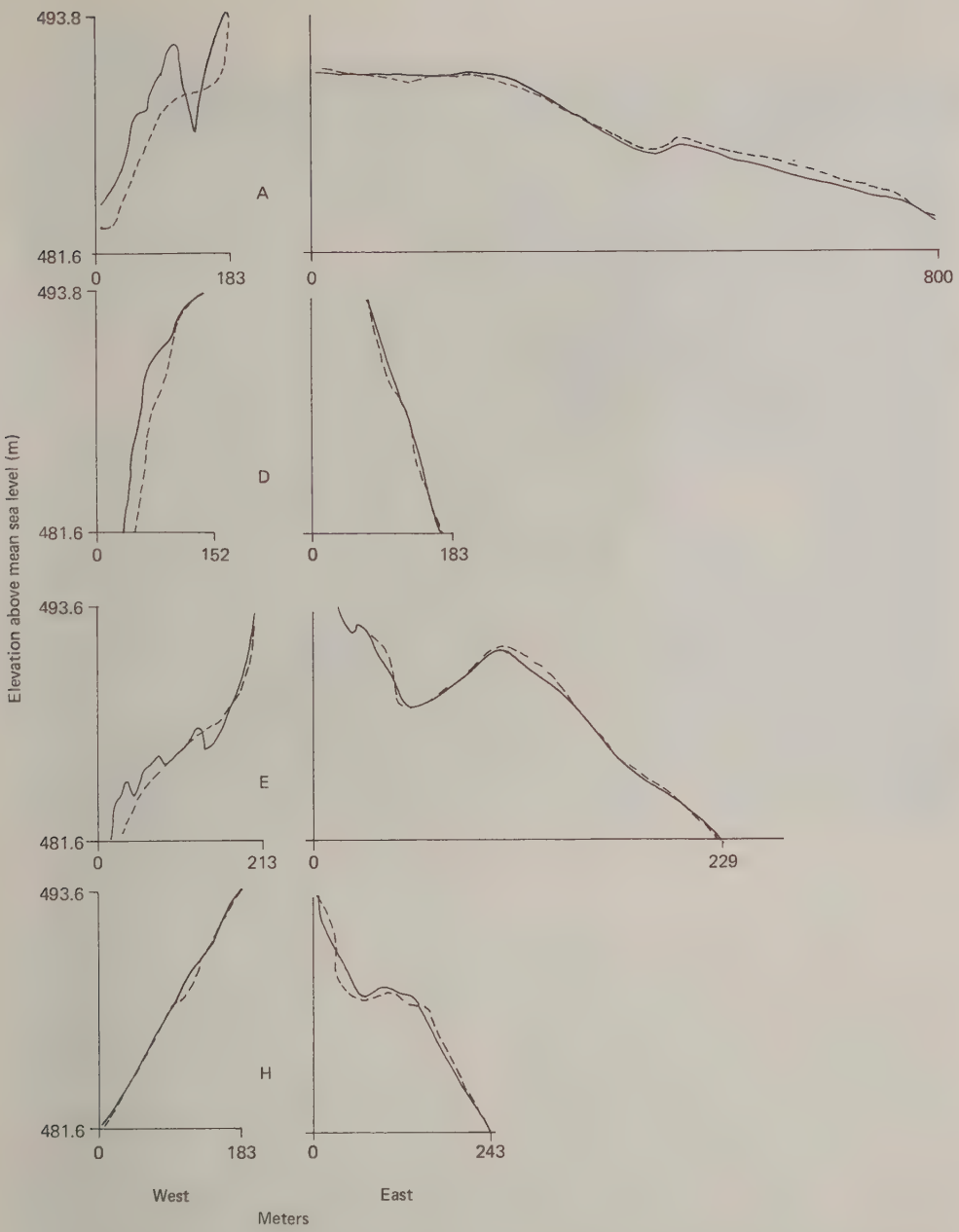

Fig. 7. Profiles of shores in lower half of Lake Oahe on west shore (panels at left) and east shore (panels at right) in 1958–59 (solid line), and in 1968 (dashed line) at stations A, D, E, and H (see Fig. 1 for locations of stations).

The shore profiles between 481.6 and 493.8 m above msl on the west shore of the downstream part of the reservoir (in Pierre shale) have followed the same trends described for Lake Fort Peck. Shore ridges and depressions were being eliminated (Figs. 7A and E). Representative mean slopes of the west shore profiles ranged between 5.9 to

Fig. 8. Wave action eroding Pierre shale shore of Lake Oahe in 1972. Bank in center of photograph was about 6 m high.

6.6% (Figs. 7A, E, and H) and 12.7% (Fig. 7D). The relatively steep slope at station D, which was caused by heavy bank-cutting that immediately preceded the measurement, will probably become more gentle. An example of bank-cutting due to wave action is shown in Fig. 8.

Much less bank-cutting has occurred along the east shore than along the west shore of Lake Oahe (Fig. 7) because the east shore is armored with deposits of heavy glacial till. Furthermore, ridges have not eroded away nor depressions filled to the same degree as along the west shore. The importance of glacial till as a deterrent to degradation along the east shore is further magnified by the fact that the prevailing winds on Lake Oahe are from the west.

Erosion of the Fox Hills sandstone and loess shore in the upstream end of the reservoir had not advanced greatly by 1968 but preliminary observations suggested that shore modification was proceeding in a manner similar to that demonstrated for other shores with deposits of glacial till. As in the other reservoirs, small inlets had been cut off by sandbars built up by littoral currents and wave action. A smooth shore configuration is expected to develop.

Shore Modifications of Lake Sharpe

Mean reservoir water levels at Lake Sharpe normally fluctuate between 432.4 and 433.0 m above msl, but fluctuations are greater in the

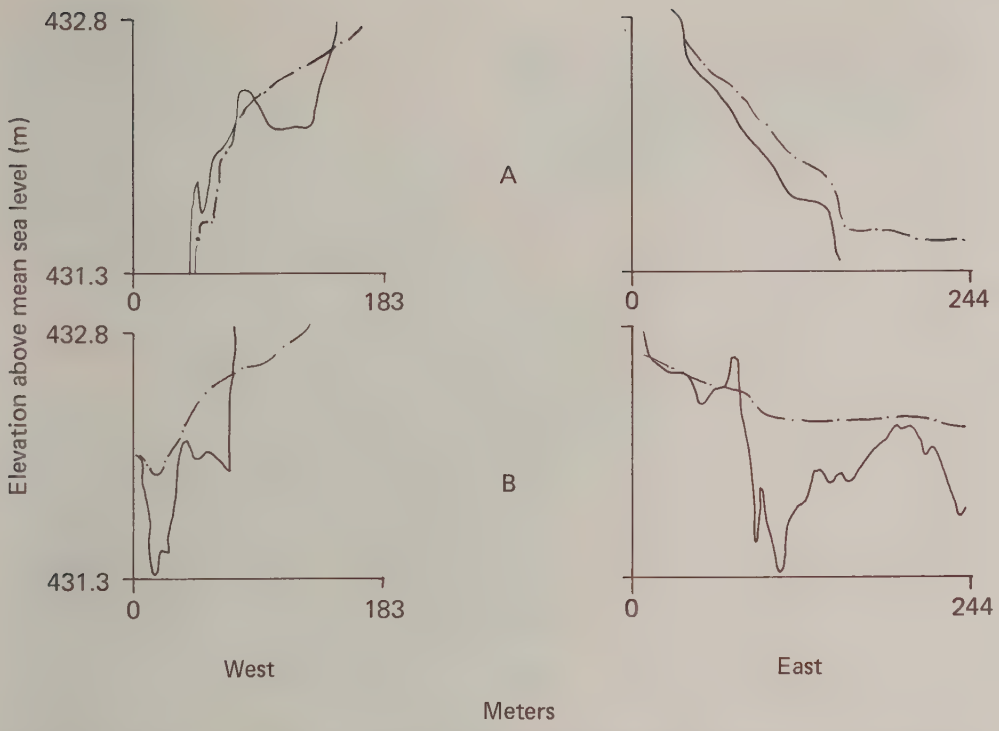

Fig. 9. Shore profiles in the upper end of Lake Sharpe in 1963 (solid line), and 1971 (broken dashed line) along east and west shore at stations A and B (Fig. 1). Note the filling in of depressions on the west shore at stations A and B and the east shore at station B.

upper 10 km, due to the peaking of inflows from the Lake Oahe powerhouse. The banks were modified considerably by 1971 (Fig. 9). The shores were smoothing out, and gentle slopes were developing along both the east and west shores.

Shore Modifications of Lake Francis Case

The Missouri River trench had eroded completely through the Cretaceous Pierre shale and was cutting into the underlying Niobrara chalk when the reservoir was impounded. The shore of Lake Francis Case has been exposed to wave action and currents since the reservoir was filled in 1952, and the steep banks in some areas indicate that shore formation is still incomplete.

The shore at the elevation of the euphotic zone (402-416 m above msl) is primarily Pierre shale, which is overlain with glacial till on the east and north shores. Wave action caused a considerable amount of slumping and landsliding during the first few years of impoundment. Erosion that developed oversteepening or undercutting of banks was considered to be the main cause of landsliding. Erskine (1973) stated that seepage pressure might be a major factor in initiating landslide activity when a reservoir is subject to drawdown, as occurs annually in Lake Francis Case (Table 2). As in the upstream reservoirs, four major changes have occurred: (1) considerable smoothing of the shore; (2) rounding off of headlands and filling in of small inlets; (3) much sloughing of shale banks; and (4) armoring of glacial deposits on the north or east shores.

Considerable sloughing has taken place in the downstream part of the reservoir (stations A, B, C, Fig. 1) at the 414.5-m elevation

Table 4. *Changes in width of Lake Francis Case at elevations 408.4 m above sea level (elevation 1 in left column of table) and 414.5 m (elevation 2) from 1957 to 1967 and 1957 to 1973 at different localities.*[a]

Station and elevation	Width (m) in 1957	Changes in width 1957–67	Changes in width 1957–73
A			
1	2,256	-3.0	0.3
2	2,341	22.2	25.6
B			
1	1,970	9.8	5.2
2	2,223	32.6	69.2
C			
1	1,279	17.1	3.7
2	1,487	32.0	79.6
D			
1	1,112	-1.8	5.5
2	1,442	3.7	7.9
E			
1	1,273	0.9	-73.5
2	1,750	13.1	11.9
F			
1	1,369	-45.1	-45.1
2	1,741	-14.0	-1,120.7
G			
1	852	-246.0	-325.8
2	1,573	4.9	5.8
H			
1	255	-88.7	-231.3
2	2,075	-26.5	-17.7

[a]See Fig. 1 for locations of stations.

(Table 4). Up to 1973, sloughing had not decreased at stations B and C.

Considerable aggradation has occurred in the vicinity of the White River Arm (Fig. 1, D and E) of the reservoir, and at stations F, G, and H in the upstream part of the reservoir (Table 4). This deposition occurred before the impoundment of Lake Sharpe in 1963.

It appears that slope modification in Lake Francis Case has often depended on the location of the channel within the reservoir; currents are generally strong, width is relatively narrow (1.6–2 km), and fluctuations in water level are large. Where the channel was near shore, bank-cutting was heavy and there was no evidence that gentle slopes were developing; the mean slope was 28% for Pierre shale (Fig. 10D, west shore), and 10% for glacial till over shale (Fig. 10B, east shore). Armoring by glacial till probably reduced degradation.

Shores away from the main channel developed gentle slopes. The mean slope was 3% in the downstream part of the reservoir (Fig. 10B, west shore) and 2.9% in midreservoir (Fig. 10D, east shore). Bank-cutting was minor on these gentle slopes.

In the upper end of the reservoir (Fig. 10H), cutting occurred on the channel (east) side, and a more gentle slope (7.3%) developed on the opposite (west) bank. On all shores, the slopes were smoothed as a result of the eroding of ridges and filling of depressions.

Shore Modifications of Lewis and Clark Lake

The principal changes in the shore of Lewis and Clark Lake have been the elimination of inlets and the filling in of the mouths of intermittent streams by littoral currents and wave action. The shores, composed of Niobrara chalk overlain with alluvium, have been less severely cut than the shores in the upper reservoirs. Because of the reservoir's shallowness (mean depth, 4.8 m), and the presence of strong currents and heavy wave action, gentle (6–10%) slopes have developed in many areas. The reservoir has developed into a semiriverine environment.

After a number of intermittent creeks had been cut off by littoral drift over a 6-year period (Fig. 11), the U.S. Army Corps of Engineers reopened several by removing the sandbars at the mouths to provide protected areas for boaters and for fish spawning habitat. However, the bars were reformed within a year. Heavy flooding in tributary streams from rain or snowmelt did not remove sandbars from the mouths of cutoff embayments. The widening of a protected stream mouth by the cutting off of banks and the elimination of headlands occurred in one stream mouth (near Gavins Point) that in 1956 was well protected from wave action, and had a mean depth of about 3 m and a firm bottom (Fig. 12). By 1970 the area had become exposed to wave action, the mean depth had decreased to about 1 m, and the bottom was composed of fine silt and sand. Much of the new substrate was probably brought there by the tributary stream.

In the upper reaches of Lewis and Clark Lake, certain trends became evident in formation of the main stem river delta. The channel lost its sinuosity along the south bank, and

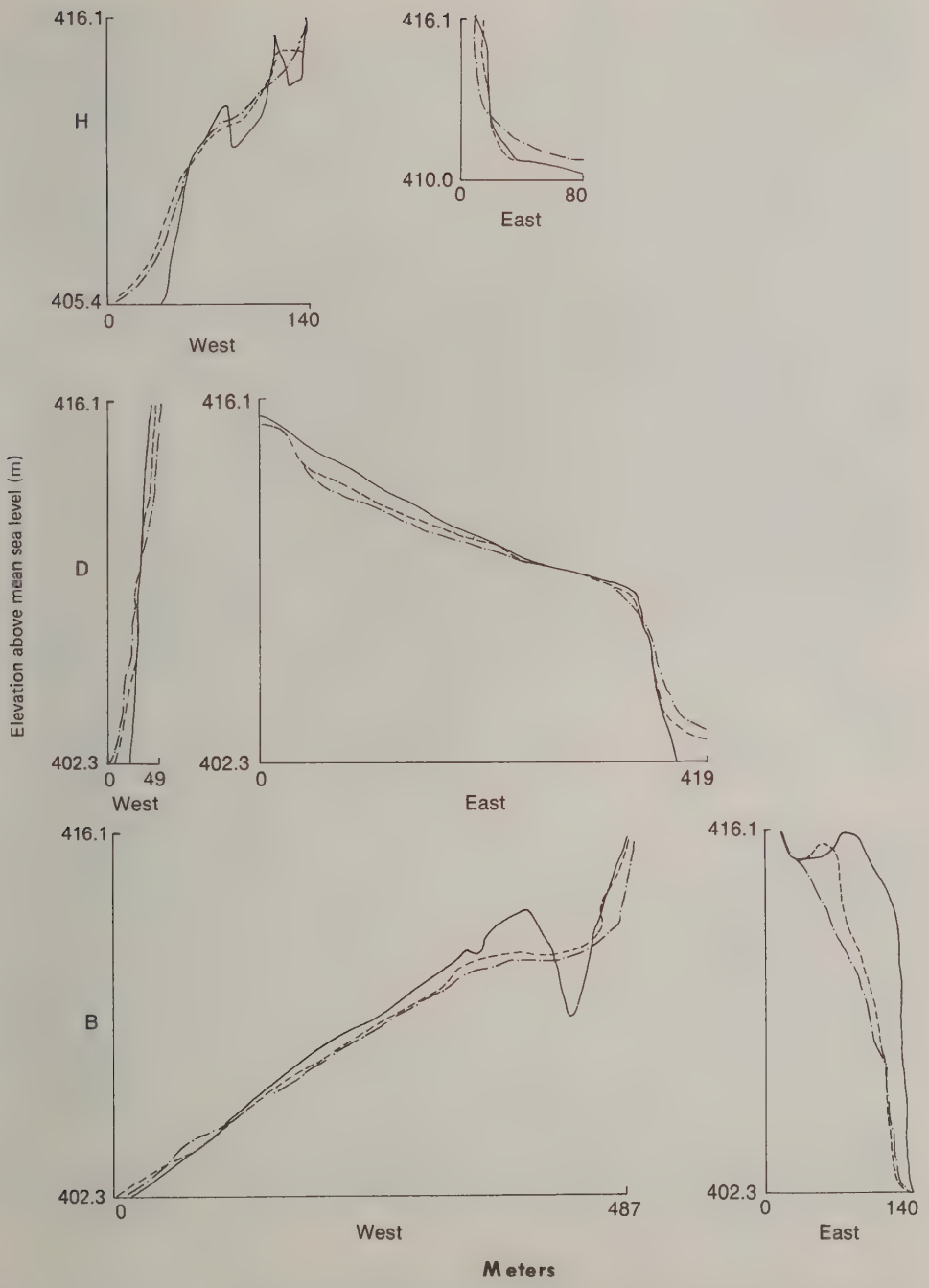

Fig. 10. Shore profiles of Lake Francis Case measured in 1953 (solid), 1957 (dashed), and 1973 (alternate dots and dashes) on west shore (panel on left) and east shore (panel on right) at stations B, D, and H (see Fig. 1 for locations of stations).

Fig. 11. Aerial views of the Charley Creek area of Lewis and Clark Lake in 1961 (left) and 1974 (right). The small intermittent stream near the top of the photograph was partly isolated from the reservoir in 1961, due to littoral drift, and was completely isolated in 1974. Also, note the increased smoothing of the shoreline at the mouth of this small stream between 1961 and 1974. In the large stream near the lower center of the photograph sandbars were forming on both sides of the stream mouth; note the increase in length between 1961 and 1974.

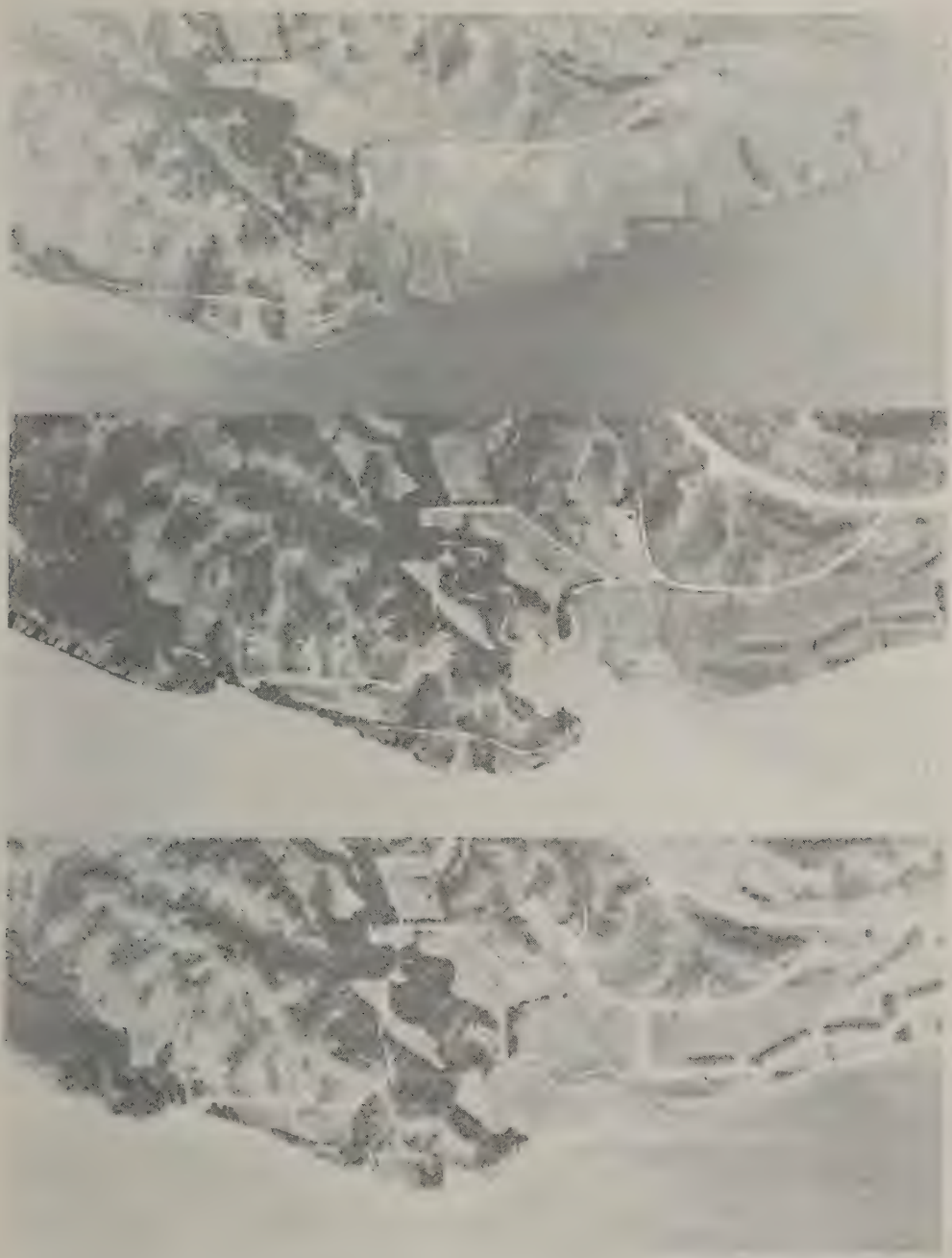

Fig. 12. Aerial views of Gavin's Point area of Lewis and Clark Lake in 1956 (top), 1964 (middle), and 1970 (bottom) showing the progressive widening of the protected stream mouth and the smoothing of the shore.

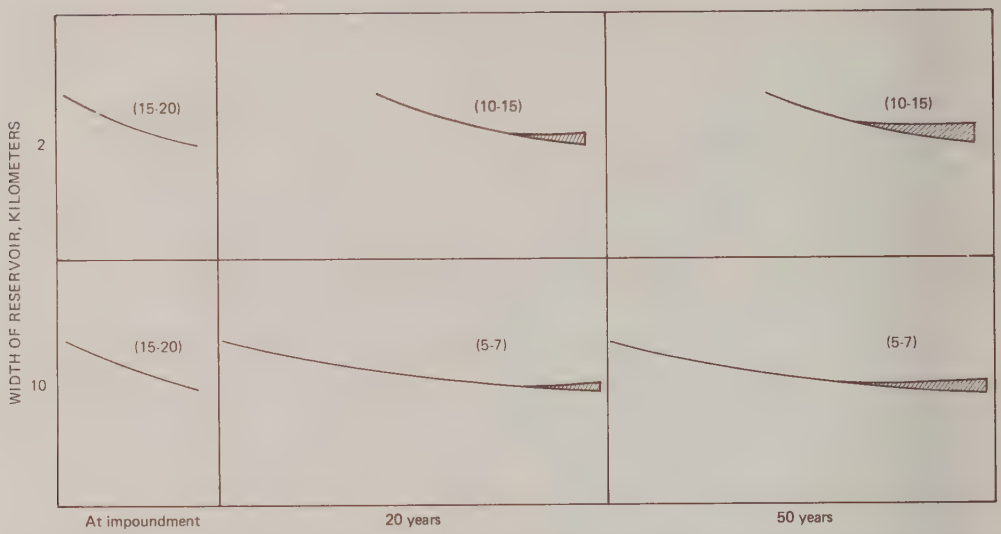

Fig. 13. Generalized trends in shore modification and sedimentation (hatched areas) on shale shores at two representative reservoir widths after different periods of impoundment. Slope ranges (percentages shown in parentheses) did not change significantly during the period from 20 to 50 years after impoundment.

dense stands of cattail (*Typha*) developed in shallow water and on islands. There has been little consolidation of the alluvial deposits, primarily because they consist mostly of sand.

Trends in Shore Modifications of Missouri River Reservoirs

Three trends have been identified in shore modification of the Missouri River reservoirs. First, small inlets and intermittent streams became sealed off by sediment delivered by waves and littoral currents. Most of this action seemed to take place during the first 20 to 25 years of impoundment. Beaches partly formed during that period further slowed the changes in shore configuration. When barrier beaches at the mouths of embayments were reopened by dredging they often were plugged again by the continuing supply of littoral drift sediments, and the quiet-water habitat inside the barrier was again isolated from the reservoir.

Second, mean shore slopes that developed were related to the width of the reservoir and offshore depths. Gentle (5–7%) slopes developed in wide (10–20 km) sections of reservoirs, and steep (10–15%) slopes in narrow (2–4 km) sections (Fig. 13). This trend, which was most evident along shale shores, was a result of wave action. Evidence from Fort Peck Lake suggests that once shale shores become stabilized, they retain their slope and configuration throughout the life of the reservoir. The sediment inflow after the shore modification period comes from tributary streams or the Missouri River, and not from shore degradation. Large annual water level fluctuations, like those that occur in Lake Francis Case, delay the stabilization of shale shores.

Third, glacial till reduced degradation by armoring the shore. It appears that these reservoirs will develop into bodies of water with little shore diversity, except for that created by tributary streams or by the shape of the Missouri River channel at the time of impoundment.

Fish Population Changes in Relation to Shore Modifications

My discussion of the relations between shore modification and fish populations is

confined to the reservoirs for which data are available on fish population changes during the early years of impoundment—Oahe, Sharpe, Francis Case, and Lewis and Clark. Although the physical data on shore modification processes indicated variation among the six main stem reservoirs, there was enough commonality in all reservoirs—e.g., the smoothing of shorelines—to suggest that the broad relations between fish populations and shore development apply to the entire reservoir system. The development of firm causal relations between fish abundance and shore changes is not possible, because such important ecological factors as water management and weather varied concurrently during the shore modification process. Therefore, my interpretation of the probable influence of shore modification on populations of the major species of fish (Table 5) is necessarily based in part on subjective judgment.

Table 5. *Common and scientific names of fishes mentioned in the text.* (From Bailey 1970)

Common name	Scientific name
Paddlefish	*Polyodon spathula*
Gizzard shad	*Dorosoma cepedianum*
Goldeye	*Hiodon alosoides*
Northern pike	*Esox lucius*
Carp	*Cyprinus carpio*
Emerald shiner	*Notropis atherinoides*
River carpsucker	*Carpiodes carpio*
Smallmouth buffalo	*Ictiobus bubalus*
Bigmouth buffalo	*Ictiobus cyprinellus*
Blue sucker	*Cycleptus elongatus*
Black bullhead	*Ictalurus melas*
Channel catfish	*Ictalurus punctatus*
Flathead catfish	*Pylodictus olivarus*
White bass	*Morone chrysops*
Largemouth bass	*Micropterus salmoides*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
Yellow perch	*Perca flavescens*
Sauger	*Stizostedion canadense*
Walleye	*Stizostedion vitreum vitreum*
Freshwater drum	*Aplodinotus grunniens*

Several workers have documented the effects of shore changes on fish reproduction and abundance in the reservoirs. Their studies suggested that reduction of quiet-water embayments, degradation of littoral habitat along the main reservoir shore and in large embayments, and reduction of shore vegetation decreased the abundance of 10 species (Table 6): white crappie, black crappie, smallmouth buffalo, bigmouth buffalo, carp, largemouth bass, black bullhead, yellow perch, northern pike, and gizzard shad. However, the walleye benefited from shore modifications in Lakes Sharpe and Francis Case because the glacial gravel and rubble exposed were suitable for spawning substrate (Nelson and Walburg 1977).

In discussing the effects of shore modifications on fish, I consider vascular vegetation first because reproduction of many fish species is closely related to the presence of vegetation. Data on the relations between shore modification and vascular vegetation from Lake Sakakawea are also reviewed. I then relate changes in abundance of 16 common fish species to their reproduction requirements and to shore modifications. Finally I relate changes in abundance of the 16 fish species to commercial and sport fishing and to reservoir fish population changes.

Effects of Shore Modification on Vascular Vegetation

The Missouri River reservoirs have few habitats conducive to the growth of vascular vegetation. Aquatic vegetation has developed in Lakes Sharpe and Lewis and Clark—reservoirs with little water level fluctuation—but is sparse to nearly absent in Oahe and Francis Case. In Lewis and Clark Lake, most aquatic vegetation has developed on alluvial delta deposits in the upper end of the reservoir. Little has developed along the rubble or chalk areas that make up most of the reservoir shore; both substrate and wave action are probably responsible. A few protected areas with heavy silt deposits have small stands of smartweed (*Polygonum*). In Lake Sharpe, most vegetation has developed in areas of reduced current; little has grown along shores derived from shale. Small areas of pondweed (*Potamogeton*) have been recorded along the lower east shore of Lake Oahe, where the water is exceptionally clear (mean Secchi disk measurement about 2.3 m). Fluctuating water levels, together with unsuitable substrate and turbidity along the shore, will prevent signifi-

Table 6. *Summary of species of fishes in which documented decreases in abundance have accompanied changes in shore habitat during the early years of impoundment in four Missouri River reservoirs.*

Ecological change, and lake	Species	Reference
Reduction in quiet water embayments due to siltation and cutting off by sandbars		
Lewis and Clark	White crappie	Walburg (1976)
Degradation of littoral habitat along reservoir due to siltation and erosion		
Lewis and Clark	Smallmouth buffalo, bigmouth buffalo, carp	Walburg (1976)
Francis Case	White crappie, largemouth bass	Walburg (1977)
Degradation of littoral habitat in large embayments due to erosion		
Oahe	Black bullhead, yellow perch, black crappie, white crappie, northern pike	June (1976)
Reduction of flooded vegetation on shores		
Oahe	Northern pike, bigmouth buffalo, carp, yellow perch	Gabel (1974)
	Carp, black crappie, white crappie	June (1976)
Francis Case	Carp, bigmouth buffalo, northern pike, smallmouth buffalo, gizzard shad	Gasaway (1970)
	Yellow perch	Nelson and Walburg (1977)
Sharpe	Carp, bigmouth buffalo, smallmouth buffalo	Elrod and Hassler (1971)

cant development of aquatic vegetation in these reservoirs. Most vegetation in the fluctuating reservoirs—Sakakawea, Oahe, Francis Case—will consist of terrestrial vegetation that develops on reservoir shores during periods of low water. The vegetation becomes flooded when water levels are higher and furnishes substrate for fish reproduction and cover for young fish and fish food organisms.

Studies on Lakes Sakakawea and Oahe (Stanley et al. 1973) provided some insight into the problems of developing vegetation on reservoir shorelines. The Fort Union formation, plus a thin layer of glacial till, formed nearly the entire shore of Lake Sakakawea, and the shore was remarkably uniform in soil type and chemistry. There was essentially no vegetation along the steep, eroding cliffs and glacial till beaches. Factors that prevented vegetation development on exposed areas were wave action, water level fluctuation, and lack of organic soil where armoring had occurred. In protected embayments, vegetation appeared to be controlled by water levels and wave action. Stanley et al. (1973), who selected 50 transects (mostly in protected embayments in areas where vegetation was present) for analysis of plant species distribution and percent cover, found that neither the percentages of nitrogen, organic matter, or silt and clay, nor degrees of slope significantly influenced percentage of cover or species diversity in the zone of annual water level fluctuation. Most plant species were grasses, but lady's thumb (*Polygonum persicaria*) and curly dock (*Rumex crispus*) were common.

Small embayments that supported shore vegetation at the time of impoundment were isolated from the main body of the reservoir by sandbars; Stanley et al. (1973) found vegetation to be sparse or absent in these isolated embayments. Water level fluctuations were not timed for suitable germination for some plant species, but wave action appeared to be the principal reason for the scarcity of vegetation on many study sites; the shores did not have suitable substrates for the production of vegetation.

In Lake Oahe the clay shores along the west bank supported little vegetation, although western wheatgrass (*Agropyron smithii*) grew in some protected areas. Stanley et al. (1973) reported that the percentage of total cover and diversity of vegetation on the Lake Oahe shore was positively correlated with the percentage of sand in the soil. The mean and (in parentheses) standard deviation of the Shannon–Wiener indices of plant diversity on various soil types were as follows: sandy loam, 1.74 (0.80); loam, 1.22 (0.74); silt loam,

Table 7. *Spawning and nursery habitat types commonly used by 16 major fish species in Missouri River reservoirs, their abundance, and their expected future* (A = abundant; C = common; L = limited; R = rare).

Habitat type	Fish species that use this habitat	Abundance of habitat by reservoir in 1974				Expected future of habitat
		Oahe	Sharpe	Francis Case	Lewis and Clark	
Tributary streams, areas in reservoir with heavy current, sections of river between reservoirs	Walleye, sauger, channel catfish, white bass, goldeye, river carpsucker	A	L	L	A	Will remain nearly constant
Wave-exposed shores with firm sand or rubble bottom—common where glacial till is exposed	Walleye, emerald shiner, white bass	A	A	A	L	Will increase
Open water, but primarily where wave action is not great	Freshwater drum	A	A	A	A	Will decrease slightly
Wave-exposed shores of soft clay or shale but with stumps or brush	Yellow perch	C	C	R	R	Will be destroyed by ice action and sedimentation
Protected embayments with or without stumps or other debris; usually with aquatic or flooded terrestrial vegetation	White crappie, black crappie, gizzard shad	C	A	R	R	Will decrease
Partly protected areas where terrestrial vegetation is inundated	Northern pike, bigmouth buffalo, smallmouth buffalo, river carpsucker, carp, yellow perch	R	R	R	R	Will decrease (amount will depend on water level management programs)

1.20 (0.84); and clay, 0.92 (0.64). It was also shown that the extensive reworking of shores, particularly the sealing off of small inlets by sandbars, had adversely affected vegetation. Although fluctuating water levels exerted considerable control on vegetation abundance in any given year, shore formation processes had the most significant effect over a long period.

Ilina and Gordeyev (1972) found that beaches that developed from shore erosion in the USSR were not suitable for growing terrestrial plants when reservoirs were lowered. On Lakes Sakakawea and Oahe, cattle grazing was also a significant factor in preventing the development of vegetation in some areas (Stanley et al. 1973).

Fish Species and Reproduction Requirements

Shore development during the early years of impoundment of a reservoir may affect individual fish species by changing the quality or quantity of spawning and nursery habitat, or by influencing growth and survival through alteration of the food supply or the severity of predation. However, no data are available on the relation of growth, mortality, or food to shore modification. Because of the primary importance of fish reproduction in sustaining a fish population, the present analysis is limited to a comparison of the loss or gain of fish spawning and nursery habitat with fluctuations in abundance of 16 common fish species in Lakes Oahe, Sharpe, Francis Case, and Lewis and Clark. Growth and mortality data, when available, are mentioned in general terms.

The spawning and nursery habitats used by the 16 common fish species in these reservoirs can be grouped into six general types (Table 7). The first three—streams or sections of reservoirs with strong current, exposed sand or rubble shoreline, and open water—will assuredly be available throughout the life of each reservoir. The fourth—soft clay or shale with stumps or brush—will disappear because of erosion and the burying of stumps by sediment. The fifth—protected embayments—will

become rare because of the erosion of headlands (Fig. 11) and the formation of sandbars across the mouths of embayments. The sixth type—partly protected embayments with flooded vegetation—will decrease in abundance for at least three reasons: (1) The shore substrates derived from shale and those derived from armoring that occurs when glacial till is exposed to wave action are the predominant types in the entire system; both substrates include little organic matter. (2) Water levels during the year (or years) before the year of fish spawning must be low enough during the summer to allow vegetation to develop. Some plant species may develop during June–August, whereas others may require an entire growing season (May–September). (3) The water levels must be raised early enough during the spring of the fish spawning season to flood this vegetation. Thus at least 2 years of suitable water levels are needed for the development and use of this habitat. It is difficult to maintain this sequence consistently because annual runoff varies widely, and the reservoirs are managed primarily for flood control, power generation, and navigation.

The 16 fish species have been grouped in four categories, according to the degree that shore modification has apparently affected abundance through altering spawning and nursery habitat: (1) adversely affected; (2) moderately affected; (3) unaffected; and (4) benefited. The gears used for collections, years of sampling, and units used to compute catch per unit effort (CPE) for adult and young-of-the-year (YOY) fish are listed in Table 8. Mean annual CPE's are used as indexes of fish species abundance. Walburg (1969) considered these indexes to be a valid method for estimating relative fish abundance if the fishing gears, units of effort, sampling locations, and times of sampling are consistent from year to year. Except for variations in units of fishing effort, these conditions were met. All year-to-year changes in a given reservoir were based on catches with a single type of gear (Table 8).

In assessing possible cause-and-effect relations between shore modification time and fish species abundance, one must consider the years that fish sampling was conducted in relation to the age of the reservoir. Data for Lakes Sharpe and Oahe were collected during the early years of impoundment, whereas those from Lakes Lewis and Clark and Francis Case were collected 10 or more years after the reservoirs reached operating water levels (Tables 2 and 8).

Fish Species Adversely Affected

Seven species that require either quiet water habitat or flooded vegetation for spawning or nursery grounds have decreased in abundance in all reservoirs: white crappies, black crappies, bigmouth buffaloes, smallmouth buffaloes, gizzard shad, yellow perch, and northern pike.

White crappies and black crappies have similar habitat requirements for reproduction; both have decreased greatly in all reservoirs (Tables 9 and 10). In Lake Oahe, the largest number of YOY fish of both species was captured in 1967, the year in which the reservoir first reached its normal operating level and flooded previously uninundated prairie. Few young were taken after 1968 and few adults after 1969. Most YOY crappies were captured in the upper ends of the west shore embayments (Beckman and Elrod 1971), where Pierre shale forms the shore. Bank sloughing and eroding of headlands have reduced the quiet, protected water areas; this habitat loss is believed to be one of the principal factors responsible for the decrease in abundance of crappies.

In Lake Sharpe, most YOY and adult crappies have been captured in Hipple Lake, an inundated lakelike part of the submerged river in the upper end of the reservoir which has not been affected significantly by shore erosion. Hipple Lake has a gently sloping shore, and vegetation.

Gasaway (1970) reported low crappie catches in Lake Francis Case after 1959, and few have been captured since 1967 (Tables 9 and 10). Quiet-water habitat has decreased, and the water level fluctuations allow little development of vegetation. Recent efforts have been made to manage water levels for vegetation development but evaluation of the results of these efforts is incomplete.

In Lewis and Clark Lake, the catches of YOY white crappies were low after 1966 (Table 10) and few YOY black crappies were captured after 1963 (Walburg 1976). Adult

Table 8. *Methods of collection, units of catch per unit of effort (CPE), months and years of sampling, and range in number of units of effort for years sampled, for adult and young-of-the-year fishes from Missouri River reservoirs.*

Lake and size group of fish	Gear[a]	Unit of fishing effort	Sampling period	Range in units of effort among years	References
Oahe					
Young of the year	30.5-m BS	Number per haul	June-Sept. 1965-74	204 to 334 hauls	Beckman and Elrod (1971); June (1976)
Adult	10.7-m SBT	Number per hour of trawling	Aug.-Sept. 1965-74	9.8 to 35.9 hours	Nelson and Boussu (1974); unpublished data
Sharpe					
Young of the year	30.5-m BS	Number per haul	June-Sept. 1967-74	120 to 136 hauls	Method in Beckman and Elrod (1971); unpublished data
Adult	106.7-m GN	Number per overnight set	June-Sept. 1965-74	59 to 91 sets	Elrod and Hassler (1971); unpublished data
Francis Case					
Young of the year	30.5-m BS	Number per haul	July-Aug. 1966-79	77 to 156 hauls	Gasaway (1970); Walburg (1977)
Adult	106.7-m GN	Number per overnight set	June-Aug. 1967, 1970, 1973	95 to 179 sets	Gasaway (1970); Walburg (1977)
Lewis and Clark					
Young of the year[b]	30.5-m BS	Number per haul	June-Sept. 1965-79	30 to 82 hauls	Nelson et al. (1968); Walburg (1976)
	8.2-m OT	Number per 10 min haul	July-Sept. 1965-74	56 to 100 hauls	Nelson et al. (1968); Walburg (1976)
Adult[c]	2.7-m TN	Number per overnight set	Sept.-Oct. 1966-72	112 to 140 sets	Walburg (1969, 1976)
	106.7-m GN	Number per overnight set	Sept.-Oct. 1966-72	68 to 102 sets	Walburg (1969, 1976)

[a]BS = bag seine; GN = gill net (experimental); SBT = semiballoon trawl; OT = otter trawl; TN = trap net.
[b]Bag seine used for measuring CPE of gizzard shad and emerald shiner, and otter trawl for other species.
[c]Trap net used for measuring CPE of white bass, river carpsucker, bigmouth buffalo, smallmouth buffalo, freshwater drum, black crappie, and white crappie, and gill net for other species.

black crappies and white crappies decreased after 1967 and showed little evidence of increased abundance up to 1972 (Table 9). Siefert (1969) found limited reproduction in boat marinas, but most of the quiet-water spawning habitats have been lost, primarily because sandbars have formed across the mouths of embayments.

The population of bigmouth and smallmouth buffaloes in all reservoirs has been dominated by a few strong year classes (Moen 1974; Elrod and Hassler 1971; Gasaway 1970; Walburg and Nelson 1966). In Lakes Sharpe, Francis Case, and Lewis and Clark, these year classes were produced during the first several years of impoundment or when new land was inundated. In Lake Oahe, large areas of new prairie were flooded in 1959, 1962, and 1965, and strong year classes were produced during these years. Above-average reproduction of bigmouth buffaloes was recorded in Lake Oahe in 1973 and 1974, Lake Sharpe in 1972, and Lake Francis Case in 1971 (Table 10). However, survival of fish of these year classes has been low. Because sampling for YOY was not conducted during any of the early years of impoundment, when strong year classes were produced in Lakes Lewis and Clark, Francis Case, or Sharpe, it is not possible to evaluate the significance of the catches in later years. Abundance of adult buffaloes generally decreased in all reservoirs (Table 9).

Few YOY gizzard shad survive their first winter in any Missouri River reservoir, and the species is not present in the system upstream from Lake Sharpe. Adult gizzard shad were rarely captured in any of the reservoirs. Bailey and Allum (1962) noted that the species here is at the northern edge of its range, and Walburg (1964) showed that the number of days of ice cover was associated with winter survival in Lewis and Clark Lake. Reproduction takes place in protected areas of embayments, which have decreased in all the reservoirs. Most gizzard shad collected in Lake Sharpe have been captured in the Hipple

Table 9. *Mean annual CPE of adult fish where reproduction was affected to different degrees by shoreline development in Lakes Oahe, Sharpe, Francis Case, and Lewis and Clark, 1965-74.*[a] (See Table 8 for methods, units of CPE, and sources.)

	Adversely affected					Moderately affected				Unaffected				Benefited
Reservoir and year	White crappie	Black crappie	Bigmouth buffalo	Smallmouth buffalo	Yellow perch	Northern pike	River carpsucker	Carp	Sauger	White bass	Goldeye	Channel catfish	Freshwater drum	Walleye
Oahe														
1965	10.6	8.0	9.1	7.6	965.8	2.2	25.5	283.3	14.6	1.8	9.1	2.9	11.3	13.8
1966	1.2	36.8	2.8	0.8	231.2	9.2	7.6	178.0	6.8	11.2	7.2	0.4	3.2	21.6
1967	28.0	11.7	3.8	1.2	113.4	2.3	9.6	108.7	4.7	11.5	15.3	3.0	1.2	12.2
1968	14.4	20.7	10.7	6.3	66.9	2.4	23.0	223.1	7.4	28.0	20.1	2.0	8.4	27.3
1969	4.0	7.6	8.7	3.0	22.3	1.1	9.6	90.3	9.4	6.0	4.1	4.3	2.9	15.0
1970	5.3	0.4	2.3	1.1	10.9	0.4	2.3	58.4	2.0	4.3	5.7	1.4	0.1	5.7
1971	1.3	0.6	2.4	0.9	10.9	0.6	9.0	75.0	2.0	5.6	1.3	1.9	1.7	17.0
1972	0.1	0.4	0.4	0.3	6.9	0.0	8.3	67.0	6.3	4.0	4.1	1.4	4.0	22.1
1973	0.0	0.0	3.1	1.6	11.3	0.6	8.3	197.0	9.6	4.1	6.3	9.9	9.7	57.1
1974	0.0	0.0	0.1	0.6	17.9	0.0	5.1	137.7	4.7	2.3	4.0	5.1	4.4	46.3
Sharpe														
1965	1.4	0.2	1.1	0.8	1.7	10.4	9.6	5.8	3.3	0.1	5.8	7.4	0.3	4.8
1966	0.6	0.2	1.3	0.5	2.6	5.0	12.0	7.1	1.8	0.4	6.7	6.9	0.2	8.6
1967	0.7	0.1	1.8	0.5	9.5	2.5	11.3	6.9	3.4	0.3	6.8	3.9	0.5	17.3
1968	0.8	0.0	1.7	0.4	7.3	1.8	10.5	7.7	3.4	0.1	5.4	7.7	0.4	22.6
1969	0.3	0.0	1.3	0.6	1.6	0.7	9.7	7.3	2.9	T	3.2	6.9	0.6	19.9
1970	T	0.0	1.5	0.4	1.2	0.3	9.3	4.8	2.7	T	3.3	8.4	0.6	23.0
1971	0.0	0.0	1.0	0.4	1.6	0.2	9.3	4.8	2.1	T	2.7	8.4	0.4	31.2
1972	T	T	1.1	0.6	0.9	0.1	8.2	6.1	1.5	0.1	2.0	6.4	0.4	23.6
1973	T	T	0.7	0.2	1.7	T	6.2	6.8	1.0	0.1	2.8	7.1	0.6	29.1
1974	0.0	0.0	1.0	0.4	2.2	0.0	5.3	5.0	1.6	0.0	2.4	4.0	0.8	29.2
Francis Case														
1967	0.1	T	0.1	0.2	3.6	0.2	3.1	2.9	1.1	0.2	4.5	3.9	0.8	4.1
1970	0.1	T	0.5	0.7	1.6	0.2	9.7	5.4	1.6	1.1	16.6	7.7	1.4	14.1
1973	0.2	0.1	0.3	0.3	1.7	0.1	4.0	4.2	0.7	0.9	10.0	5.9	1.5	9.8
Lewis and Clark														
1966	10.9	1.2	19.0	4.5	0.2	T	9.4	3.3	6.1	9.1	1.9	4.0	10.1	1.2
1967	15.0	1.3	11.7	5.0	0.1	T	18.0	2.1	3.9	12.3	0.5	2.9	19.2	0.8
1968	5.4	0.4	10.1	5.0	0.0	0.0	20.2	2.4	4.4	5.0	0.6	3.0	14.1	1.8
1969	4.4	0.1	8.5	2.3	0.2	T	19.1	2.1	4.0	5.7	0.6	2.5	11.0	1.2
1970	7.8	0.2	6.0	2.9	0.5	T	10.8	2.1	4.0	9.5	0.4	3.1	7.8	1.6
1971	4.7	0.2	4.7	1.1	0.5	T	12.1	2.0	4.1	3.8	0.4	3.1	9.9	1.6
1972	3.2	0.1	4.2	0.7	0.3	T	7.3	1.4	4.1	3.3	1.0	5.4	7.5	1.5

[a]T = less than 0.05 fish.

Table 10. *Mean annual CPE of young-of-the-year fish where reproduction was affected to different degrees by shoreline development in Lakes Oahe, Sharpe, Francis Case, and Lewis and Clark, 1965–74.* (See Table 8 for methods, units of CPE, and sources.[a])

	Adversely affected							Moderately affected			Unaffected					Benefited
Reservoir and year	White crappie	Black crappie	Bigmouth buffalo	Smallmouth buffalo	Gizzard shad[b]	Yellow perch	Northern pike	Emerald shiner[c]	River carpsucker	Carp	Sauger	White bass	Goldeye	Channel catfish	Freshwater drum	Walleye
Oahe																
1965	1.4	8.6	4.8	3.1	0.0	96.3	0.6	31.9	0.6	4.3	1.3	8.6	1.1	0.1	0.4	1.7
1966	2.6	1.5	0.7	T	0.0	171.1	T	41.8	2.4	1.1	0.2	5.3	0.5	0.1	1.1	0.2
1967	34.1	28.2	0.3	T	0.0	585.2	T	43.0	0.0	0.1	T	32.0	0.1	0.0	0.1	0.2
1968	22.2	15.1	0.8	0.1	0.0	596.8	0.0	60.2	0.7	0.5	T	4.1	T	0.0	0.7	0.1
1969	1.4	3.6	2.5	0.8	0.0	310.4	0.4	20.7	0.2	2.5	0.1	35.4	0.1	0.0	0.6	0.6
1970	0.2	0.3	1.2	0.1	0.0	165.2	T	25.5	0.7	0.5	0.1	46.4	0.5	T	1.7	0.4
1971	0.4	1.0	0.8	T	0.0	55.0	0.2	32.7	0.4	2.4	0.1	25.6	1.3	0.3	1.7	0.3
1972	1.1	0.2	0.4	0.1	0.0	54.1	T	20.4	0.1	0.1	0.3	18.3	0.9	T	0.6	1.1
1973	0.8	0.2	6.5	0.1	0.0	24.7	0.0	18.2	0.5	0.2	0.1	21.8	1.3	T	1.8	0.4
1974	0.8	0.1	9.3	0.0	0.0	21.4	T	3.1	0.0	0.5	0.0	19.4	0.1	0.0	1.3	0.4
Sharpe																
1967	2.2	1.2	0.1	0.5	46.4	58.3	0.0	15.6	0.2	0.1	0.5	2.0	3.3	T	0.2	0.9
1968	2.2	1.8	0.2	0.2	188.3	150.9	T	26.9	0.1	0.1	1.3	0.2	0.3	T	0.2	7.6
1969	0.1	0.1	0.3	T	175.6	76.6	T	21.4	0.1	T	0.3	0.7	0.0	0.0	0.1	5.5
1970	1.0	8.8	0.5	0.1	117.9	19.9	0.0	60.0	T	0.1	0.4	0.3	T	0.0	0.5	2.9
1971	0.1	1.1	0.1	T	102.8	8.6	0.0	33.6	0.3	0.0	0.1	0.2	0.3	0.0	0.2	2.3
1972	T	0.2	1.7	0.5	40.3	20.5	0.0	3.3	0.2	0.1	0.1	0.4	T	0.0	0.2	3.2
1973	T	0.2	1.3	0.3	91.3	20.1	0.0	0.6	0.1	0.1	T	0.3	0.2	0.0	1.6	2.2
1974	0.0	0.0	0.0	0.0	66.0	33.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
Francis Case																
1966	42.4	31.5	1.4	0.1	0.8	14.8	0.0	2.2	T	T	T	1.5	0.1	T	2.2	0.3
1967	15.4	4.6	0.8	1.1	17.5	132.4	0.0	42.8	0.3	1.2	0.1	10.9	0.1	0.2	6.2	0.9
1968	T	0.1	0.0	0.0	18.6	52.5	0.0	13.4	0.4	T	0.0	46.3	0.2	0.0	6.4	0.4
1969	T	T	0.2	T	5.1	8.5	0.0	8.6	T	T	0.0	47.8	0.0	T	1.6	0.5
1970	T	0.0	0.1	T	4.3	1.8	0.0	23.2	0.1	0.0	0.0	5.6	0.0	0.0	1.3	0.1
1971	T	0.3	1.6	0.5	T	115.7	0.0	21.6	T	0.4	T	14.7	0.0	T	0.1	0.9
1972	2.6	0.3	0.7	0.3	22.8	10.6	0.0	3.7	0.2	0.1	0.0	11.7	T	0.0	2.4	0.1
1973	T	0.0	0.8	0.6	3.1	7.2	0.0	4.2	0.1	0.0	0.0	6.1	T	T	1.7	0.2
1974	0.0	0.0	T	0.2	23.6	4.0	0.0	7.2	0.2	0.0	0.0	10.3	T	T	3.1	0.2
Lewis and Clark																
1965	11.1	T	T	0.0	63.6	0.9	0.0	151.7	0.4	T	5.3	18.7	0.0	18.3	117.5	0.2
1966	9.5	0.1	0.1	0.1	45.2	0.5	0.0	82.6	0.7	T	7.1	11.5	0.0	21.8	69.4	0.4
1967	4.1	0.1	0.1	0.1	40.6	0.0	0.0	49.0	0.5	0.1	1.7	31.6	0.0	6.1	38.4	0.2
1968	4.1	0.0	0.0	0.0	10.7	9.4	0.0	44.5	0.6	0.0	5.1	18.4	0.0	7.2	61.4	0.7
1969	4.1	T	0.2	0.1	19.9	10.0	0.0	32.0	0.5	1.0	3.9	35.2	0.0	0.9	27.8	2.3
1970	0.1	T	0.0	0.1	3.2	2.0	0.0	42.0	0.7	T	4.7	4.8	0.0	10.5	41.5	4.7
1971	0.5	0.2	0.0	0.0	2.0	0.5	0.0	26.1	1.0	0.2	4.0	9.4	T	3.6	31.0	2.2
1972	4.3	0.1	0.1	0.2	9.4	2.5	0.0	23.9	0.5	0.1	2.7	16.5	0.0	5.4	27.4	1.3
1973	2.4	T	0.1	0.1	7.4	6.8	0.0	20.1	1.1	0.5	3.6	25.7	0.0	10.0	371.0	1.3
1974	2.8	0.0	T	0.0	14.0	18.8	T	37.8	0.2	0.3	18.6	16.2	0.0	23.6	246.4	3.1

[a]T = less than 0.05 fish. [b]Not present in Oahe. [c]Includes all ages.

Lake area. In Lake Francis Case, most reproduction has occurred in the upper end, where several road embankments have created quiet-water habitat. Little quiet-water habitat now exists in Lewis and Clark Lake; reduction in this habitat appears to be the principal cause for the progressive downward trend shown by gizzard shad since impoundment (Table 10).

The decrease in flooded vegetation and submerged brush and trees has presumably been responsible for the decrease in abundance in yellow perch (Tables 9 and 10). In Lakes Oahe and Sharpe, YOY were most abundant in 1968 and declined thereafter. Beckman and Elrod (1971) found that the highest concentration of yellow perch in Lake Oahe during the early years was in the west shore embayments; however, shale shores here have undergone rapid degradation. In Lake Francis Case, yellow perch reproduction was good in 1967 and 1971; during both years, water levels were high enough during May to flood terrestrial vegetation. Apparently water level manipulation can provide suitable yellow perch spawning habitat in this fluctuating reservoir.

Hassler (1970) stated that strong year classes of northern pike in Lakes Oahe and Sharpe were associated with stable to rising water level and temperature, flooded vegetation, and calm weather during the spawning season. The numbers of northern pike in Lakes Lewis and Clark and Francis Case have always been small. The absence of flooded vegetation due to the unfavorable shore substrate has apparently been responsible for the poor reproduction and relative scarcity of adult northern pike in Lakes Oahe and Sharpe, at least since 1966 (Table 9).

Fish Species Moderately Affected

Emerald shiners, river carpsuckers, and carp have generally declined in abundance in all reservoirs; part of this trend may be associated with shore modification processes. These species should remain common in the reservoir fish populations because of their ubiquitous spawning habit. Also, river carpsuckers and carp are long-lived species (Walburg and Nelson 1966; Elrod and Hassler 1971).

Reproduction of emerald shiners has been most successful in relatively protected areas, although the young have also been collected along exposed rocky or sandy shorelines (Fuchs 1967; Beckman and Elrod 1971). The reduction in area of small embayments and the smoothing of the shore in large embayments are probably responsible for the overall decrease of this species (Table 10). Reduction in shore diversity would also increase the probability of predation; June (1976) attributed increased predation as the primary reason for decreased abundance of emerald shiners in Lake Oahe. The species has an extended spawning season (June–August) and spawns over a wide variety of substrates. These attributes may be responsible for the occurrence of at least some reproduction every year in each reservoir.

The overall abundance of adult river carpsuckers decreased after impoundment in each reservoir, but some reproduction has occurred each year and adult abundance has remained high (Tables 9 and 10). Spawning occurs both in tributaries and on flooded vegetation. The high reproduction recorded in Lakes Lewis and Clark and Francis Case during the first few years of impoundment was probably related to the flooding of vegetation (Walburg and Nelson 1966; Gasaway 1970). The rather low but consistant reproduction recorded in all reservoirs probably reflects reproduction in tributary streams, as suggested by Beckman and Elrod (1971) for Lake Oahe and Walburg (1976) for Lewis and Clark Lake.

Reproduction of carp appears never to have been heavy in any of the reservoirs (Table 10) and the stocks of adult fish have tended to decrease in abundance in all of them (Table 9). The high catches in Lake Oahe reflect the effectiveness of semiballoon trawls for capturing carp (Nelson and Boussu 1974). The populations in each reservoir consisted largely of a few year classes produced during the early years of impoundment (Gabel 1974; Walburg 1964; Gasaway 1970; Elrod and Hassler 1971; Walburg and Nelson 1966). Because carp are long-lived, are only lightly exploited by sport and commercial fishermen, and spawn over an extended period, adult stocks can be expected to remain in these reservoirs, but probably at low levels. Growth has been extremely poor in all reservoirs;

Elrod and Hassler (1971) found that no annuli were produced during certain years in Lake Sharpe.

Fish Species Little Affected

Spawning and nursery habitat for saugers, channel catfish, white bass, goldeyes, and freshwater drum have not been affected by shore modification processes. These species spawn in tributary streams, in sections of reservoirs with heavy current, along rocky shorelines, or in open water (Table 7). Also, freshwater drum have semipelagic eggs (Swedberg and Walburg 1970). Variations in abundance of YOY and adults (Tables 9 and 10) may be attributed to shore modification, primarily through its effects on prey organisms in the food chain.

Except for reduced growth due to decreased abundance of forage fish (Nelson 1974; Walburg 1976), the sauger has not been adversely influenced by shore modifications.

Abundance of adult white bass has decreased in Lakes Oahe, Sharpe, and Lewis and Clark, but the reduction cannot be attributed to shore modification processes, because most reproduction has been in tributary streams or in sections of reservoirs with heavy currents or wind action (Beckman and Elrod 1971; Walburg 1976).

Reproduction of the goldeye has been measured commonly only in Lake Oahe, and spawning is apparently limited to tributary streams (North Central Reservoir Investigations, unpublished data). The young have been captured during most years in Lakes Sharpe and Francis Case, but spawning locations are not known.

Changes in abundance of freshwater drum and channel catfish cannot be attributed to shore development. Swedberg and Walburg (1970) suggested that the strength of year classes of freshwater drum was determined by water temperatures in spawning and nursery areas. The reduction in protected embayment habitat, where wave action is reduced, might have adversely influenced reproduction. The spawning grounds of channel catfish were not determined in any reservoir, but Starostka and Nelson (1974) found that the nursery areas in Lake Oahe were at the mouths of tributary streams. Probably most spawning occurs in tributary streams or in riverine areas.

A Fish Species Benefited by Shore Modifications

The abundance of adult walleyes has increased in every reservoir, and this species was the predominant large predator in the Missouri River system in the 1970's. The major increases occurred before 1967 in Lake Francis Case (Gasaway 1970) and before 1966 in Lewis and Clark Lake (Walburg 1964). Spawning and nursery areas increased in quality and quantity as a result of the exposure of glacial till and the armoring of shores. Reproduction has been rather regular and the abundance of adults has remained high (Tables 9 and 10). The variation in CPE for YOY walleyes among years (Table 10) is partly a reflection of the difficulty of capturing this species with the gears used (June 1976; Walburg 1976). Increases in abundance, however, have been associated with decreased growth in Lake Oahe (Nelson 1974), Lake Francis Case (Gasaway 1970), Lake Sharpe (Nelson and Walburg 1977), and Lewis and Clark Lake (Walburg 1976). Decreased growth has been associated with reduced numbers of forage fish, principally yellow perch, which are among the species that have been most adversely influenced by shore modification. Increased density of the species may also have been a factor in reducing growth rate.

Relation of Shore Modification to Commercial and Sport Fishing

Shore development has been associated with reductions in abundance of bigmouth and smallmouth buffaloes—reductions that are reflected in the commercial catches in Lakes Francis Case and Oahe through 1974 (Table 11). In Lake Francis Case, buffaloes made up 88% of the catch from 1959 to 1974; most of the fish came from year classes produced during the early years of impoundment (Gasaway 1970). In Lake Francis Case the commercial fishery was built primarily on the buffaloes. The catch of other species after 1964 was low because commercial fishermen set their gill nets only in locations where buf-

Table 11. *Annual commercial catch (metric tons) of fish in Lake Francis Case, 1959–74, and Lake Oahe, 1964–74.*[a]

	Francis Case		Oahe		
Year	Buffalo[b]	All species[c]	Buffalo[b]	Goldeye	All species[c]
1959	80.4	89.8	—	—	—
1960	219.4	264.3	—	—	—
1961	121.9	173.1	—	—	—
1962	126.7	160.2	—	—	—
1963	156.3	185.3	—	—	—
1964	117.1	154.6	145.3	—	156.5
1965	99.2	100.8	289.4	—	306.6
1966	142.7	144.7	168.8	20.9	227.4
1967	135.6	137.2	251.3	26.0	327.4
1968	51.0	55.5	226.8	40.5	342.7
1969	101.8	104.2	228.1	151.4	450.9
1970	85.0	86.9	262.1	28.0	352.8
1971	79.5	80.3	220.0	63.3	319.8
1972	57.8	58.5	154.8	121.4	319.3
1973	65.7	66.7	143.2	77.7	287.5
1974	53.5	53.9	136.5	35.9	204.6
Total	1,693.6	1,916.0	2,226.3	565.1	3,295.5

[a]Data from South Dakota Department of Game, Fish and Parks.
[b]Includes both bigmouth and smallmouth buffaloes, but mostly bigmouth buffalo (Gasaway 1970; Higham 1974).
[c]Included in the total are river carpsucker, carp, paddlefish, channel catfish, blue sucker, and flathead catfish.

Table 12. *Mean annual CPE of fish (all species) per haul of a 30.5-m bag seine in Missouri River reservoirs, 1965–74.* (See Table 8 for sampling periods.)

	Lake			
Year	Oahe[a]	Sharpe[b]	Francis Case[c]	Lewis and Clark[d]
1965	0	0	0	268
1966	260	0	101	134
1967	740	139	238	103
1968	717	388	139	59
1969	408	285	73	72
1970	246	217	39	51
1971	131	152	159	31
1972	100	75	59	39
1973	79	132	20	45
1974	59	112	54	68

[a]June (1976).
[b]North Central Reservoir Investigations, unpublished data.
[c]Walburg (1977).
[d]Walburg (1976).

faloes were most available, and fished primarily during the spring spawning season (Gasaway 1970). In Lake Oahe, buffaloes made up 68% of the harvest from 1964 to 1974; most were from year classes produced during the filling of the reservoir (Higham 1974; Moen 1974). A commercial fishery for goldeyes has also developed in Lake Oahe; this fishery should be less adversely affected by shore modification. The variation in goldeye catches (Table 11) reflects both variations in market demand and in the strength of different year classes (Higham 1974; North Central Reservoir Investigations, unpublished data). Large percentages of other species were caught in Lake Oahe because fishing was conducted from spring to fall in a variety of habitats (Higham 1974).

Sport fishing has been less adversely influenced than commercial fishing by the apparent effects of shore modification on fish populations. The sport fishery has been supported primarily by walleyes, saugers, northern pike, white crappies, black crappies, white bass, and channel catfish. Carp, goldeyes, paddlefish, largemouth bass, and a few other species were occasionally caught. Shore modification has been associated with increases in abundance of walleyes (Table 9) but decreases in growth. Northern pike, black crappies, and white crappies have decreased to low levels. The growth rates of saugers, white bass, channel catfish, and other species commonly caught by sport fishermen have decreased. The growth rate of predator species has declined in Lakes Oahe, Francis Case, and Lewis and Clark, presumably because fewer forage fish were available along the shores. The decrease in abundance of small fishes along the shores was shown by catches in seines (Table 12). The trend in CPE for small fish has been continuously downward in Lake Oahe since 1968, the year after the reservoir reached operating levels. Catches in Lake Sharpe decreased to a lesser degree. Catches in Lake Francis Case were high in 1967, but were much lower than during the early years of impoundment (Gasaway 1970). Catches in Lewis and Clark Lake decreased after 1965, and Walburg (1976) showed that catches in 1956-64 were much higher than those in later years.

In Lewis and Clark Lake the fish population biomass index trends show that sport species decreased much less than did nonsport species from 1966 to 1972 (Fig. 14). The main cause for the trend in nonsport species was in the decrease of large (1.5 to 4.5 kg) bigmouth and smallmouth buffaloes; both species were apparently adversely affected by shore modification processes. Of the sport fish

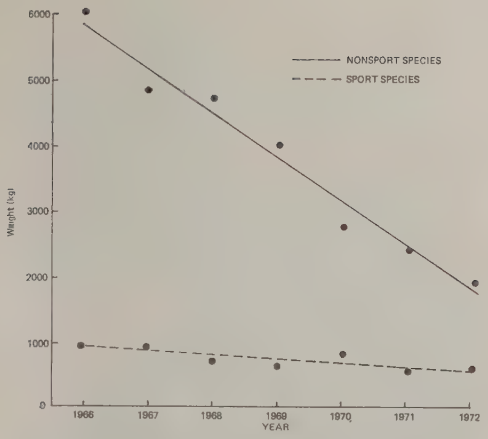

Fig. 14. Estimated total biomass indexes for nonsport fish species (carp, river carpsucker, smallmouth buffalo, bigmouth buffalo, freshwater drum) and sport species (channel catfish, white bass, white crappie, sauger, walleye) from Lewis and Clark Lake, 1966–72. From Walburg (1976).

species, only the white crappie appeared to have been adversely affected by shore modification in this lake, and the 1966–72 data were collected after a large decrease in white crappies had already occurred (Walburg 1976).

Reservoir Fish Population Changes Following Impoundment

Jenkins (1977) noted that sharp fluctuations and increases in fish standing crops usually occur in new impoundments in response to rising water levels and the release of nutrients from newly flooded land. He wrote that environmental conditions and fish biomass tended to stabilize after 5 to 10 years. Also, the finding by Jenkins (1976) that allochthonous detritus from the watershed was the primary food source for fish in Oklahoma reservoirs supported the idea that newly flooded land may be responsible for high fish biomasses in new impoundments, and for lower biomasses in ensuing years.

The Missouri River reservoirs also had higher fish densities immediately after impoundment than in ensuing years (Walburg 1976, 1977; June 1976). There are no data to relate high fish densities after impoundment and lower fish densities in later years to the abundance of detritus. There is evidence, however, that high zooplankton densities in Lake Francis Case were associated with the flooding of formerly unimpounded land in upstream Lake Oahe (Martin and Novotny 1977). Thus, fish density trends during the early years of impoundment in the Missouri River reservoirs may have been related to the contribution of detritus from the watershed.

I have presented evidence that fish species with certain reproduction requirements—embayments, brush, or submerged vegetation on shores—decreased in abundance much more than did species that reproduced on rocky shores or in tributary streams. Shore modification processes during the early years of impoundment in Missouri River reservoirs reduced the area of embayment habitat and the amount of brush and submerged vegetation on shores. Thus, shore modifications may have been the major cause for changes in abundance of some fish species during the early years of impoundment.

Shore Modifications and Reservoir Planning

Shore modification in large reservoirs located in areas of easily erodible geological formations has not been adequately considered by planners or by aquatic ecologists. Topographic maps of reservoirs at the time of impoundment are often used to calculate morphometric measurements or indices for the entire life of a reservoir. Shores of the Missouri River main stem reservoirs have undergone rapid change during the first 20 to 25 years of impoundment, and realistic maps of reservoir shores for long-term management cannot be developed until after the major aspects of shore formation are complete. The time relation between the initial shore modification period, 20 to 25 years, and the total life of Missouri River reservoirs can be judged by viewing the estimated time in years before each reservoir fills with sediment: Fort Peck, 1,000; Sakakawea, 600; Oahe, 700; Sharpe, 390; Francis Case, 280; and Lewis and Clark, 170 (Omaha District, U.S. Army Corps of Engineers, unpublished data).

Ecological conditions during the shore modification period give a distorted picture of

the future ecology of the reservoir. Long-term planning should emphasize ecological conditions after the major geological processes of shore modification are completed—i.e., after 20 to 25 years in the Missouri River reservoirs. These processes include the destroying of small embayments, smoothing of shores due to eroding of headlands, burying of stumps and debris on shores, and armoring of shores where glacial till was present. Fish species that decreased in abundance require small embayments or shorelines with many headlands, or stumps and debris for reproduction. One species, the walleye, which spawns on armored shores, increased in abundance. Although fish reproduction was the primary biological activity I have discussed (because significant data were available), plankton and benthos production was probably also influenced by shore modification. In the development of research and management programs on reservoirs located in highly erodible areas, shore modification should be considered as a major ecological force, at least during the early years of impoundment.

Acknowledgments

The physical data on the Missouri River main stem reservoir shorelines were provided by the Omaha District, U.S. Army Corps of Engineers. The geological data on reservoir shores came from planning documents of the Corps of Engineers except where references are cited. R. Livesey, Civil Engineer in charge of sedimentation studies for the District, provided ideas, aided in data assembly, and edited an early draft. M. Tipton, South Dakota Geological Survey, and L. Duscha, Missouri River Division, U.S. Army Corps of Engineers, provided helpful editorial comments. W. Nelson, C. Walburg, and F. June, North Central Reservoir Investigations, provided many ideas and editorial comments. T. Yorke, U.S. Geological Survey, also provided editorial comments. Photographs were provided by Omaha District, U.S. Army Corps of Engineers, Fig. 5; Agricultural Stabilization and Conservation Service, U.S. Department of Agriculture, Figs. 11 and 12; and G. Hoffman, University of South Dakota, Fig. 8.

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